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Science 30

MODULE 5

Fields and Circuits

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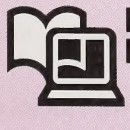
Science 30

Module 5

Fields and Circuits



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Science 30
Student Module Booklet
Module 5
Fields and Circuits
Alberta Distance Learning Centre
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Welcome to Module 5!

We hope you'll enjoy your study of Fields and Circuits.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

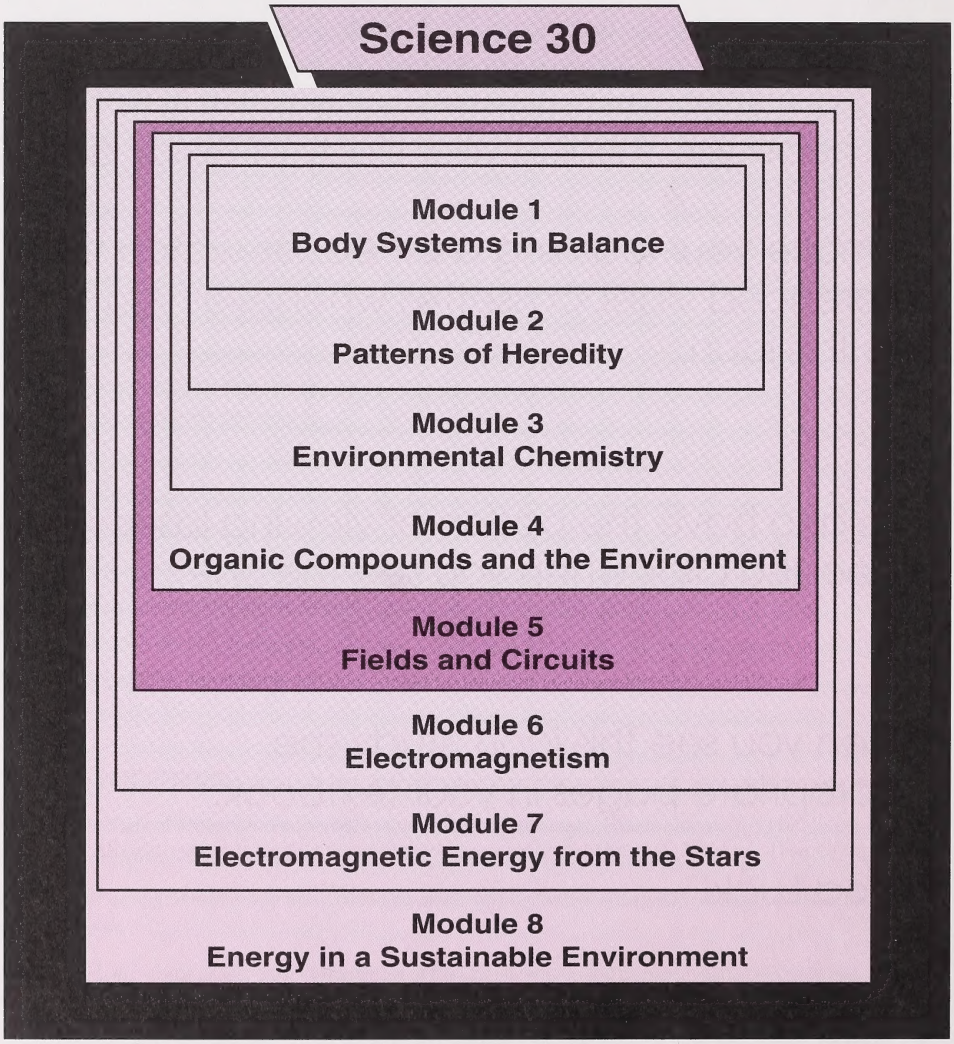
You also have the option of viewing laser videodisc clips when you see this one.

When you see this icon, study the appropriate pages in your textbook.

Good Luck!

Course Overview

This course contains eight modules. Modules 1 and 2 involve the study of the human circulatory system, defence mechanisms, the nervous system, as well as the principles of genetics. Modules 3 and 4 investigate acids and bases, organic compounds, and their effects on the environment. Modules 5 and 6 involve the study of field theory, the operation of various electrical devices, as well as some of the properties of electromagnetic waves. Module 7 focuses on the electromagnetic spectrum and its relation to the study of the Universe. Module 8 will involve the study of the various sources of energy and how a balance must be maintained between the demand for energy and the need to maintain a viable environment.



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MODULE OVERVIEW

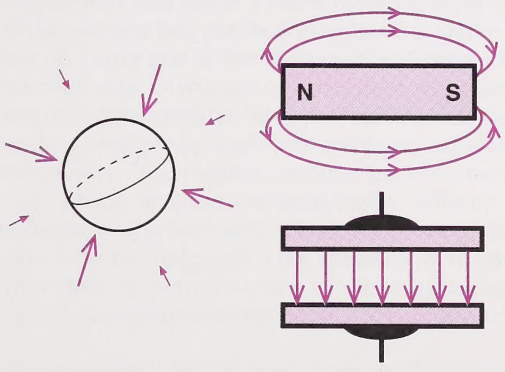
Imagine that you are walking with a friend on a winter night. The clear sky has caused the temperature to drop, but you don't mind because the fresh blanket of fluffy snow has made the evening very quiet. You glance up towards the north sky and your eyes are immediately captured by a spectacular display of colour—the aurora borealis, or northern lights. The sheets of colour are mostly shades of green, but you occasionally see streaks of blue and purple. As you continue walking, your friend asks, "What causes the northern lights?"

How would you answer this question? Would you know that part of the answer involves charged particles in the atmosphere being caught in Earth's magnetic field lines?

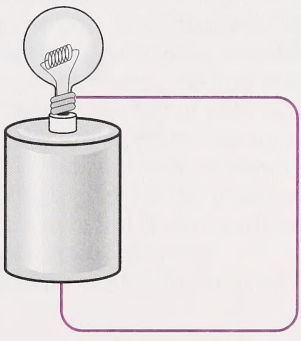
In this module you will first investigate the nature of the gravitational field, the electric field, and the magnetic field. The ideas used to study the electric field will form the basis of the second section which focuses on electric circuits.

Module 5: Fields and Circuits

Section 1: The Invisible Connection



Section 2: Using Electric Energy



Evaluation

Your mark in this module will be determined by how well you complete the assignments at the end of each section. You must complete all assignments. In this module, you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	**45 marks**
Section 2 Assignment	**55 marks**
TOTAL	**100 marks**

Section

1 The Invisible Connection

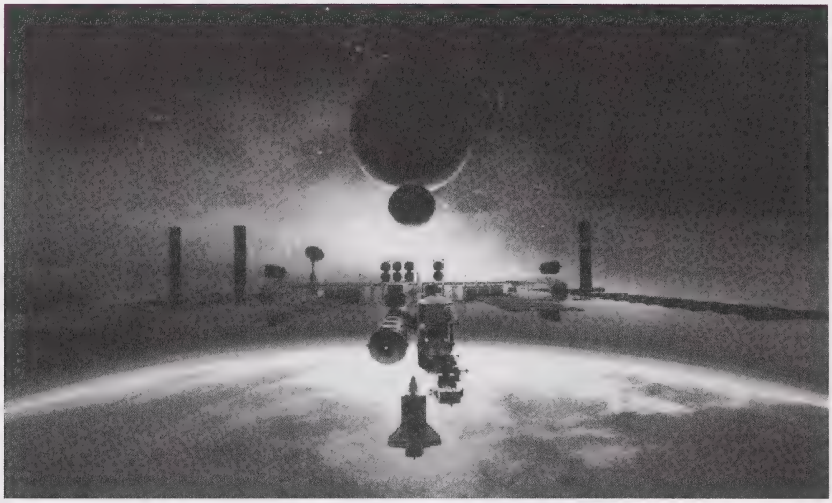
JIM WHITMER PHOTOGRAPHY

Imagine that you are at a party meeting a new group of people for the first time. You're a little nervous but you're trying hard to make a good impression. Unfortunately this ends up being one of the most accident prone and embarrassing evenings of your life. Your first sign of trouble occurs when you take off your acrylic sweater. As you walk by a mirror a few minutes later you realize that nearly every hair on the top of your head is standing straight up and they are being repelled by your shirt sleeve when you try to pat them down. You make a dash for the bathroom to straighten this out only to knock over a vase sitting on a narrow table in the hallway. After helping to pick up the pieces you apologize to the host who insists that everything is really all right but if you want to feel better why not help move the speakers to improve the sound from the stereo. Unfortunately you move one of the largest speakers beside the colour television set which completely distorts the picture on the screen.

If this happened to you it might seem like invisible hands followed you to cause mischief all night long. Of course these three events were not caused by invisible hands. The scientific explanation would attribute each mishap to a force acting through the presence of a field.

In this section you will use your previous knowledge of gravitational forces and the analysis of sample data to develop the concept of the gravitational field. This process will be used as a template as you follow a similar procedure to move from the idea of an electric force to the concept of the electric field. The section ends with an investigation that leads to an understanding of the magnetic field.

Activity 1: Gravitational Forces



NASA

Earth is often compared to a huge spaceship travelling at a terrific speed through space. It is amazing that such a large object that is travelling so fast can stay in its orbit. Why doesn't Earth fly off into space? How would you answer this question?

One answer would be to recall from your work in Science 20 that Earth is held in its orbit around the sun by the force of gravity. The size of this force can be calculated using Newton's law of universal gravitation.

Gravitational constant

$G = 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$

Force of gravity between two masses (in N) → $F_g = \frac{Gm_1m_2}{r^2}$

← Mass of one object (in kg)

← Mass of the other object (in kg)

← Distance between the centre of the masses squared (in m)

The *Visions 3* textbook uses capital *M* for *m,* when planets or the sun are involved. In this module you will use m_1 and m_2 for the masses in all cases.

1. Use the following data to calculate the force of gravitational attraction between the sun and Earth.

   mass of Earth $= 5.97 \times 10^{24}$ kg

   mass of the sun $= 1.99 \times 10^{30}$ kg

   distance from the centre of Earth to the centre of the sun $= 1.50 \times 10^{11}$ m

Check your answers by turning to the Appendix, Section 1: Activity 1.

Visions

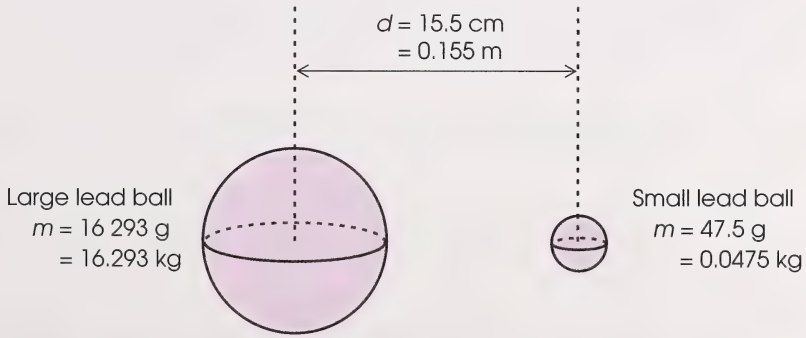
Although Isaac Newton developed this equation theoretically, it was experimentally verified by Henry Cavendish. Cavendish used a torsion balance which is a device used to measure tiny forces between two objects. A illustration of a torsion balance is shown on page 238 of your textbook. The particular balance used by Cavendish had two lead spheres that attracted each other within the enclosure. Carefully examine the illustration and caption on page 238 of your textbook before attempting the following questions.

2. Why did Cavendish use lead spheres to measure the force of gravity?

3. Why did Cavendish keep the lead spheres enclosed?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Sample results from a Cavendish-type experiment are shown in the following diagram.



The force of gravitational attraction between the two lead balls was also measured.

$$F_g = 2.15 \times 10^{-9} \text{ N}$$

If this data is substituted into Newton's law of universal gravitation, the only unknown quantity is the gravitational constant, *G*.

$$F_g = \frac{Gm_1m_2}{d^2}$$

$$2.15\times10^{-9}\ \text{N} = \frac{G(16.293\ \text{kg})(0.0475\ \text{kg})}{(0.155\ \text{m})^2}$$

$$2.15\times10^{-9}\ \text{N} = G(32.13\ \text{kg}^2/\text{m}^2)$$

$$G = \frac{2.15\times10^{-9}\ \text{N}}{(32.13\ \text{kg}^2/\text{m}^2)}$$

$$G = 6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}$$

Notice that the gravitational constant does the following two important things for the law of universal gravitation.

- *G* allows both sides of the equation to be numerically equal.
- *G* allows the units on both sides of the equation to be equal.

The gravitational constant is a very small number. If you write it as a decimal number instead of using scientific notation, it looks like this:

$$G = 6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}$$

$$= 0.000\ 000\ 000\ 066\ 7\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}$$

4. Explain how this small value of *G* will influence the force of gravity that is calculated for two objects.

5. Calculate the force of gravity between two people that are standing 1.0 m apart. Assume that each person has a mass of 65 kg. Would either person be able to easily notice this force?

Check your answers by turning to the Appendix, Section 1: Activity 1.

The preceding questions could be answered using Newton's law of universal gravitation. In each case you were able to calculate a missing quantity.

A question that remains is how one object can actually exert a force on another even though they don't touch each other. As you'll learn in the next activity, the solution to this problem required the invention of a whole new idea.

Activity 2: Gravitational Fields

After the work of Newton and Cavendish, it was possible for people to perform calculations that could describe the motion of many observable objects in the heavens. For example, if you knew all the data, calculating the gravitational force that Earth exerts on the moon would not be that difficult. The moon is Earth's natural satellite.

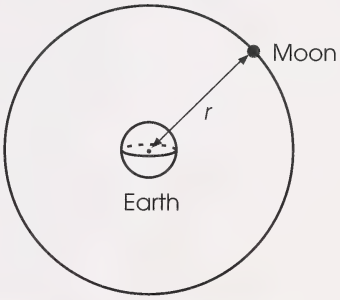
1. Use the sketch and data provided to calculate the force of gravity on the moon.

m_E (mass of Earth) $= 5.98 \times 10^{24}$ kg

m_m (mass of the moon) $= 7.34 \times 10^{22}$ kg

r (distance between Earth and moon) $= 3.80 \times 10^{8}$ m

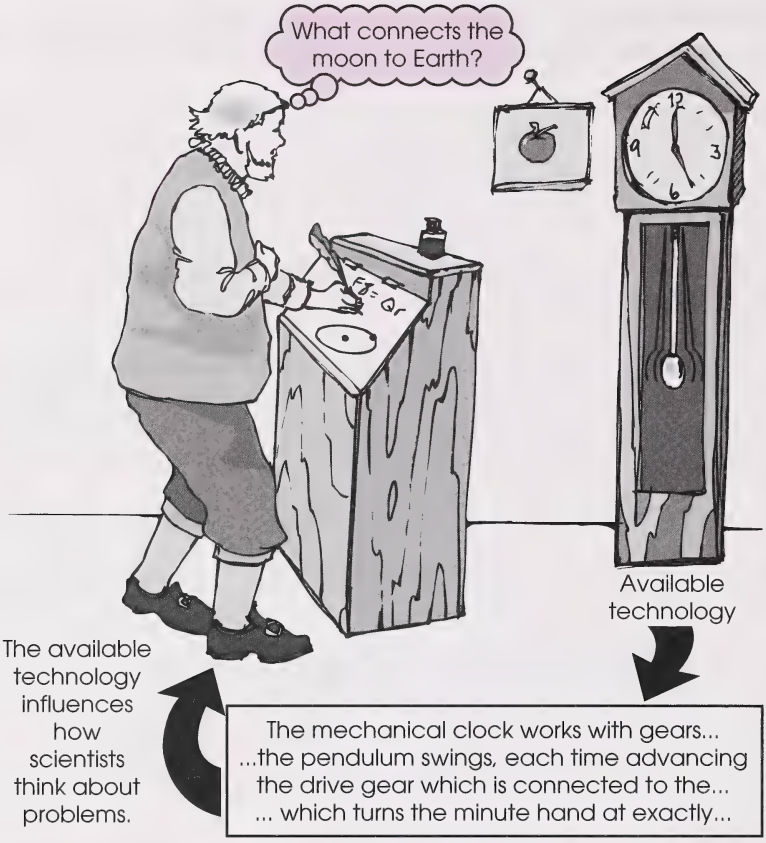
F_g (Earth's force of gravity on the moon) = ?



Check your answers by turning to the Appendix, Section 1: Activity 2.

Many people have difficulty explaining how gravitation happens. How could Earth exert such a huge force over the incredible distance between itself and its satellite, the moon?

Newton was uncomfortable with the idea that Earth could somehow exert a large force on the moon with no physical connection between them. For many years after Newton's death, other scientists shared this concern over the idea of **action at a distance**. These scientists lived in an age when all the advanced technologies were mechanical, and so they tended to look at problems from a mechanical point of view.


What connects the moon to Earth?
Available technology
The available technology influences how scientists think about problems.
The mechanical clock works with gears...
...the pendulum swings, each time advancing the drive gear which is connected to the...
... which turns the minute hand at exactly...

Since the scientists so strongly believed that there must be a connection between Earth and the moon, they invented such a connection.

THE CONNECTION BETWEEN EARTH AND THE MOON	
Property	**Rationale**
The connection is invisible.	Nobody has ever seen this connection.
The connection is almost completely undetectable.	Unlike a large rod or wire holding the moon in place, this connection can't be touched and it has no mass.
The only way that this connection can be detected is to place a mass within it; then a force on the mass will be detected.	When any object with a mass is placed above the surface of Earth and released, it is immediately forced to Earth by this connection.

gravitational field – the space surrounding a mass in which other masses within the region will experience a gravitational force

The name given to this invisible connection between Earth and the moon is the **gravitational field.**

You can learn more about the gravitational field by reading from the last paragraph on page 229 in your textbook to the middle of page 230.

2. Use examples to illustrate the differences between a scalar field and a vector field.

3. What is another name for gravitational field strength?

4. Is gravitational field a type of force?

Check your answers by turning to the Appendix, Section 1: Activity 2.

gravitational field strength – represented by a vector that indicates the force per unit of mass

As the reading in your textbook indicates, the term *gravitational field* can either refer to the invisible connection that lets one mass exert a force on another, or it can refer to force per unit mass acting on an object. In this case it is called **gravitational field strength**, and it can be represented by a vector as shown in the following equation.

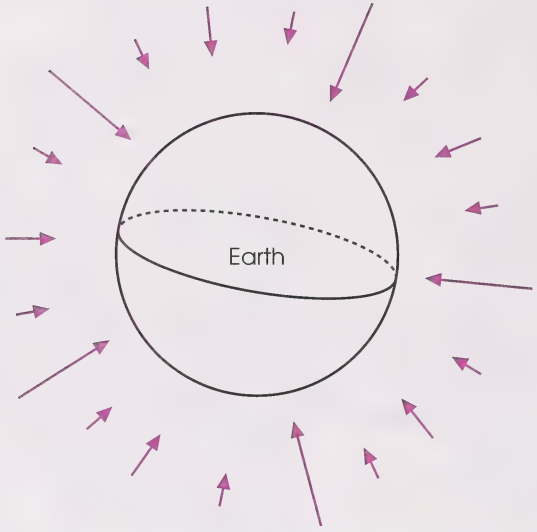
$$\vec{g} = \frac{\vec{F}_g}{m}$$

The direction of the gravitational field is the same as the direction of the gravitational force on a test mass.

The magnitude of the gravitational field is determined by dividing the force of gravity on a test mass by the mass of the test object itself. The units are N/kg.

You can get a better sense of how a gravitational field can be drawn by reading the last half of page 230 in your textbook and by closely examining the following diagram.

The Gravitational Field of Earth

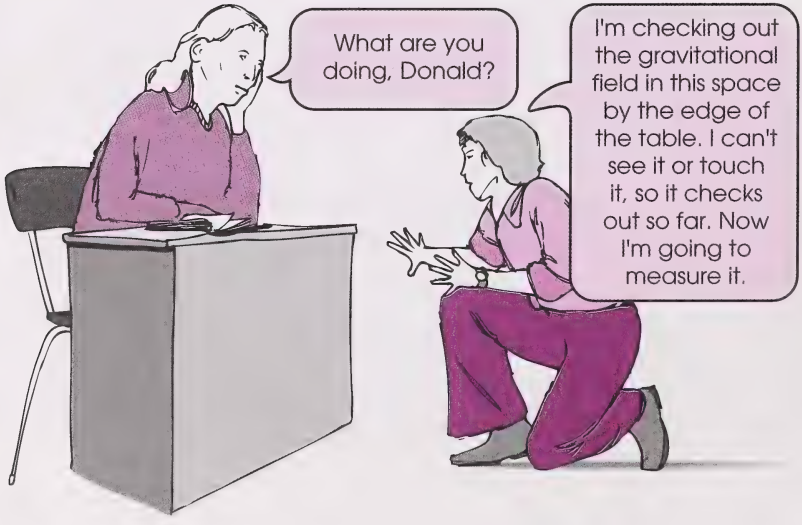


Notice that the gravitational field strength decreases as you get further away from Earth.

5. Why do the vectors representing the gravitational field strength point inward towards the centre of Earth?

6. Describe how the gravitational field strength changes if you go twice the distance from the centre of Earth.

Read the following brief account of how two students explored the gravitational field of Earth.


What are you doing, Donald?
I'm checking out the gravitational field in this space by the edge of the table. I can't see it or touch it, so it checks out so far. Now I'm going to measure it.

And how do you intend to do that? With your field detector?
Exactly right, Debbie. I'm using this can of cola as a test mass. Let's see, the spring scale reads 3.6 N. Since the mass of the whole can is 370 g, I can calculate the field strength.

7. Complete Donald's calculation of the gravitational field strength using his measurements.

Visions

The previous question shows how important it is not to confuse the terms *mass* and *weight*. Donald measured the weight of the can with the spring scale. Weight is the magnitude of the force of gravity. Donald likely used a balance to determine that the mass of the can was 370 g. You can learn more about the differences between mass and weight by reading the first two paragraphs on page 230 of your textbook again.

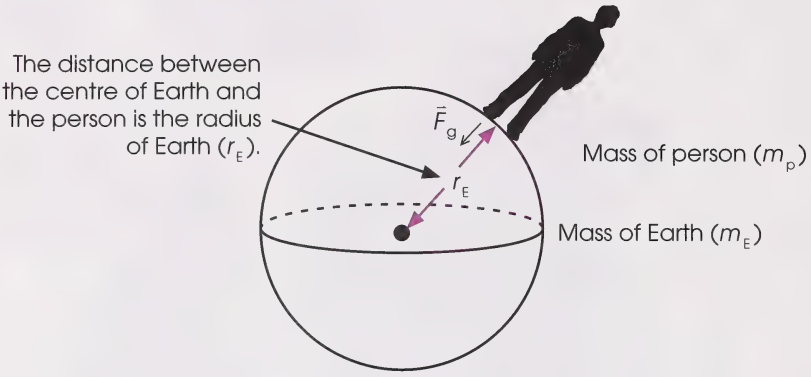
8. If weight is the measurement of gravitational force, what does mass measure?

Check your answers by turning to the Appendix, Section 1: Activity 2.

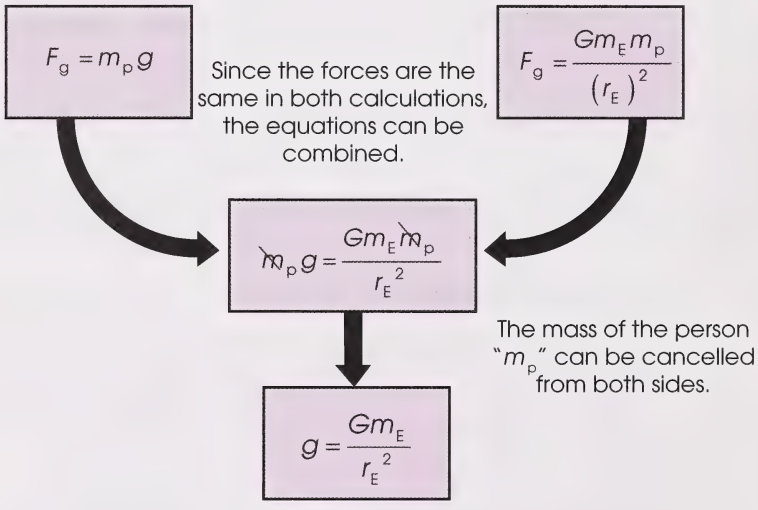
You have seen that the strength of the gravitational field can be described in terms of the force of gravity acting on a test mass. This is what Donald did in the preceding cartoon.

An alternative approach is to think of the gravitational field strength in terms of the **source** of the field. For Donald's experiment the source of the field is Earth. As the following flow chart indicates, this approach starts by thinking about the force of gravity in terms of Newton's law of universal gravitation.

Deriving Another Equation for Gravitational Field Strength


The distance between the centre of Earth and the person is the radius of Earth (r_E).
$\vec{F}_g$
r_E
Mass of person (m_p)
Mass of Earth (m_E)

The derivation begins by considering that there are two ways to calculate the force of gravity acting on a person.


$F_g = m_p g$
Since the forces are the same in both calculations, the equations can be combined.
$F_g = \frac{Gm_E m_p}{(r_E)^2}$
$m_p g = \frac{Gm_E m_p}{r_E^2}$
The mass of the person "m_p" can be cancelled from both sides.
$g = \frac{Gm_E}{r_E^2}$

This equation makes some important points about what influences the magnitude of the gravitational field on the surface of Earth.

- The mass of Earth helps to determine how strong the gravitational field is.
- Since the gravitational constant (G) is such a small number, only objects with large masses (planets, stars, and large moons) will produce a significant gravitational field.
- The further you are from Earth's centre, the smaller the value of the gravitational field due to Earth will be.

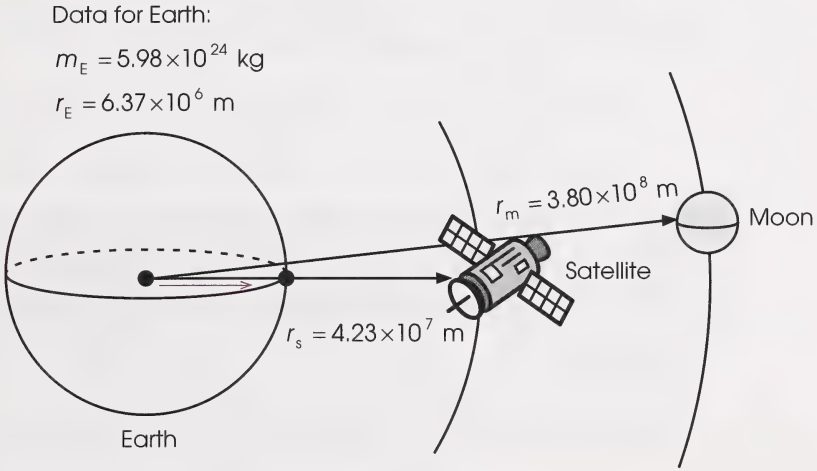
9. Use the data and information shown on the diagram which follows to complete these calculations.

   a. Calculate the strength of the gravitational field at the surface of Earth.

   b. Calculate the strength of the gravitational field at the location of the **geosynchronous satellite**.

   c. Calculate the strength of the gravitational field at the location of the moon.

geosynchronous satellite – a satellite that remains above the same point on Earth's surface



Check your answers by turning to the Appendix, Section 1: Activity 2.

Both equations for calculating the magnitude of the gravitational field for a point in space contain a mass variable, but these masses refer to different things.

$$\vec{g} = \frac{\vec{F}_g}{m}$$

This is the mass that is brought into the gravitational field. This mass is known as the **test mass**.

$$g = \frac{Gm}{r^2}$$

This is the mass of the object that is producing the gravitational field. This mass is known as the **source mass**.

If you keep these ideas straight, these equations can be very helpful in problem solving.

Visions

10. Practise using these equations by doing Practice Problems 1 and 2 on page 232 of your textbook.

The gravitational field of Earth has a significant impact on the physical environment and therefore on the life processes of organisms. You can find out more about this by reading pages 232 and 233 in your textbook. When you've finished the reading, answer the following questions.

11. Concisely explain how the gravitational field of Earth may have been indirectly responsible for the extinction of the dinosaurs.

12. What is the Banff-Jasper gravity anomaly?

13. Explain how the gravitational field helps you to maintain your bone mass.

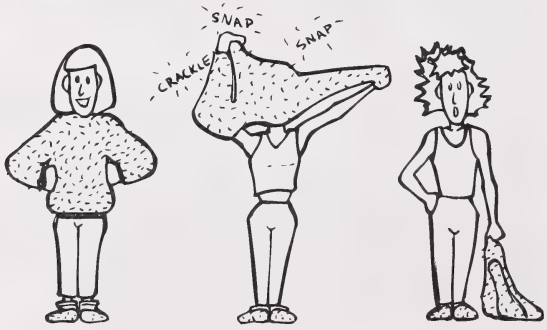
14. How do the cells in the roots of plants use the gravitational field?

Check your answers by turning to the Appendix, Section 1: Activity 2.

In this activity you have learned how to calculate the strength of the gravitational field for a given source, and you have also seen how significant the gravitational field can be for life on Earth. In the next activity you will learn similar things about the electric field.

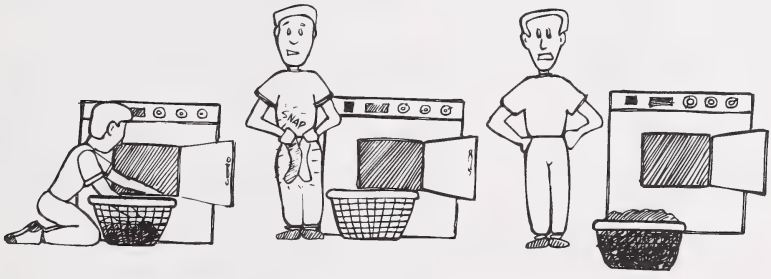
Activity 3: Electric Forces

You probably encounter the effects of static electricity on a daily basis. Which of these electrostatic phenomena are familiar to you?



Wearing a wool sweater can produce static electricity. When you take off the sweater, you can hear sparks (you can see them too if the room is dark). After you take the sweater off, your hair stands on end.

Shuffling your feet across carpet while wearing socks also produces static electricity. When you touch a metal doorknob, a spark is produced and your fingers will tingle for a while.



When you get your clothes out of the dryer, sometimes they are stuck together. When you pull the clothes apart, you can hear sparks snapping. Do you ever wonder how antistatic sheets work to reduce this?

These experiences all prove that objects do become electrically charged after rubbing and that once an object is electrically charged, it may attract or repel other objects. The effects of static electricity are easily observed, but what causes these electrostatic charges to develop in the first place?

Visions

You can find the answer to this question by reading the last half of page 235 and the top half of page 236 in your textbook. When you've completed the reading, answer the following questions.

1. Why are atoms considered electrically neutral if they are comprised of charged particles?

2. Which subatomic particle is actually transferred when an acetate strip is rubbed with a cotton cloth?

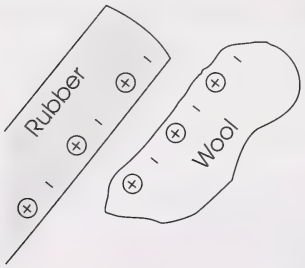
3. Imagine that two balloons have been charged by rubbing them with cloth. Describe the force that would act between the balloons in each of the following situations:

   a. Both balloons have a negative charge.

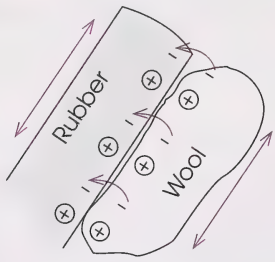
   b. Both balloons have a positive charge.

   c. One balloon has a positive charge while the other has a negative charge.

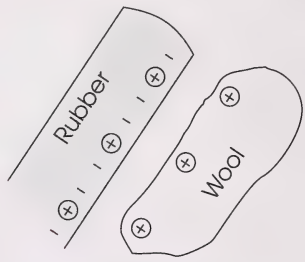
4. Study the following diagrams and use them to answer the questions.



Before rubbing, atoms of wool and rubber are electrically neutral.



During rubbing, a transfer of electrons occurs.



After rubbing, each object has gained a net charge.

law of conservation of charge – a law stating the total amount of charge in a closed system remains constant

ion – an atom that has gained or lost electrons, leaving it with a net negative or positive charge

   a. What is the purpose of rubbing objects in the formation of charged objects? Refer to the **law of conservation of charge** in your answer.

   b. Which charged particle is transferred during rubbing?

   c. Copy these headings into your notebook. Be careful to leave enough space for your answers. Write in the appropriate word or words to fill in each space.

Object	Indicate whether the object has lost or gained electrons.	Indicate the type of ion formed in the object.	Indicate the net charge on the object.
Rubber			
Wool/Fur			

   d. Why can't the positive nuclei be transferred during the rubbing of solid objects?

Check your answers by turning to the Appendix, Section 1: Activity 3.

electric conductor – a material through which charge easily moves

electric insulator – a material through which charge does not easily move

Once an object attains a net charge, this charge may remain on the surface of the object or it may move freely within the object. How the electrons behave in the substance is used to classify all substances into two main categories: **electric conductors** and **electric insulators**. These terms are usually shortened to conductors and insulators when the context is known to be electricity.

The video series *Electricity* contains a ten-minute program called "*Conductors and Insulators.*" This video is available from the Learning Resources Distributing Centre or may be obtained through your local school or library. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. Note that you may have to periodically stop the tape in order to record your answers.

5. a. What type of force holds the electrons within an atom?

   b. Are all the electrons attracted to the nucleus with the same amount of force?

6. a. What is a conductor?

   b. Explain why certain electrons are able to move freely between neighbouring atoms in a conductor?

   c. Give three examples of substances that are good conductors?

7. a. What is an insulator?

   b. Explain why electrons are not able to move freely between neighbouring atoms in an insulator.

   c. Give three examples of substances that are good insulators.

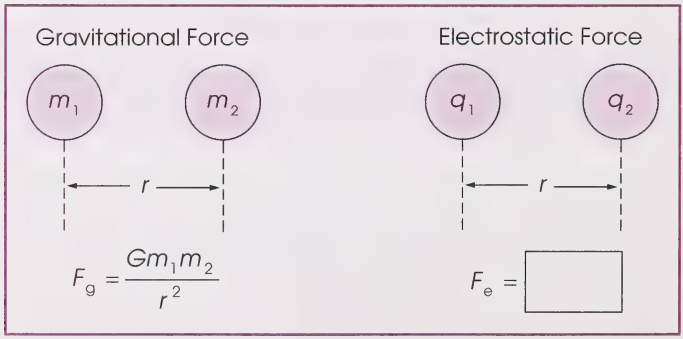
Check your answers by turning to the Appendix, Section 1: Activity 3.

The modern theory of electrostatics can explain why an object becomes charged and how this charge becomes distributed in a substance. Once the object is charged, it can be used to charge other objects. Charles Augustin de Coulomb used this idea as he experimentally explored the nature of the force between charged objects.

Coulomb did not begin his work on determining the electric force law on his own. As the following timeline indicates, much of the essential groundwork had already been done by other scientists.

Date	Scientist	Contribution to Coulomb's Work
1687	Isaac Newton	Newton published his great book *Mathematical Principles of Natural Philosophy*. This book included his three laws of motion and his law of universal gravitation $\left(F_g = \frac{Gm_1m_2}{r^2}\right)$.
1775	Benjamin Franklin	Franklin noticed that a small cork inside a hollow, charged can experienced no force. The same cork experienced a force on the outside of the can. He wrote to Joseph Priestley and asked him to repeat the experiment.
1776–1777	Joseph Priestley	Priestley verified Franklin's results and realized a connection to Newton's law of universal gravitation. Newton, in his famous book, showed mathematically that an object would experience no force of gravity inside a hollow planet. This was a consequence of the fact that the force of gravity varies as the inverse square of distance. Priestley instantly likened the cork to the object and the hollow can to the hollow planet. Priestley suggested that this indicated that the force of electricity could also be an inverse square law.

You should now be able to use your knowledge of the law of universal gravitation and Priestley's suggestion to speculate about the nature of the electrostatic force.



8. Which variables are likely to influence the magnitude of the electrostatic force?

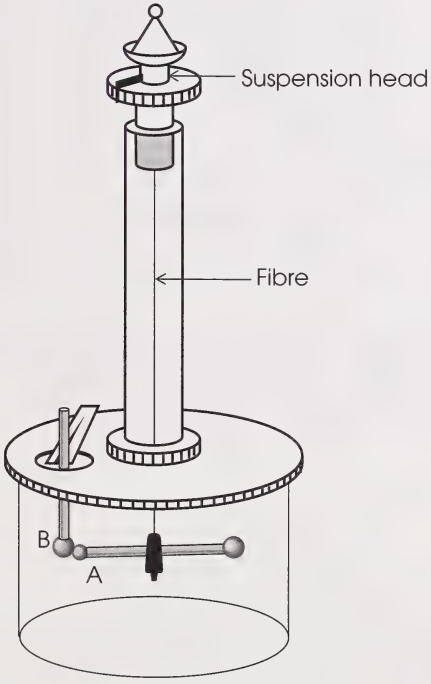
9. How would increasing the size of both charges likely influence the magnitude of the electrostatic force?

10. How would increasing the distance between the two charges likely influence the magnitude of the electrostatic force?

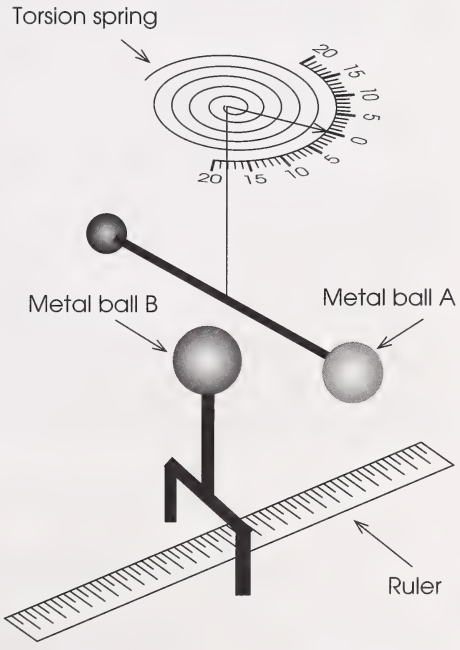
Check your answers by turning to the Appendix, Section 1: Activity 3.

Visions

Although the kind of thinking used to answer the preceding questions is very helpful as a starting point, it is important to verify these educated guesses with data collected from an experiment. Coulomb did this with his torsion balance, which is shown in Figure 7.3 on page 238 of your textbook. A detailed drawing of the torsion balance is shown in the following diagrams.



In Coulomb's torsion balance a horizontal, balanced rod is suspended by a thin, stiff fibre of silver wire. The wire twists when a force is exerted on Ball A, which is shown at one end of the rod. The twisting of the wire can be measured at the suspension head at the top, which indicates the force acting on Ball A.



A simplified schematic diagram of the torsion balance is shown. This simplified version shows how the variables of distance of separation (r) and charge (q) could be used to measure the electrostatic force (F_e).

In the next investigation you will use simplified diagrams of Coulomb's apparatus to help determine the nature of the electrostatic force.

Science Skills
- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

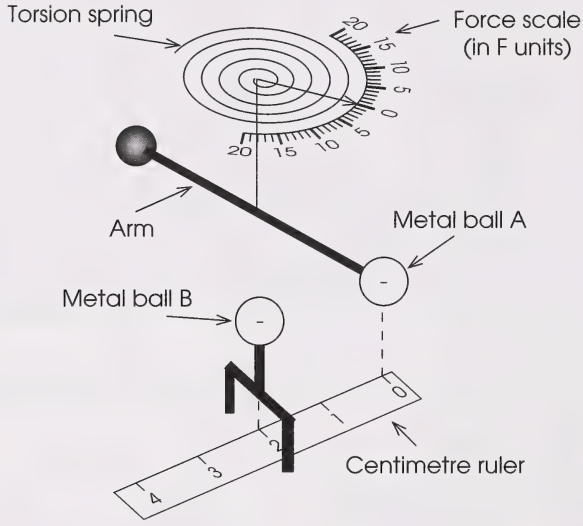
Investigation: The Effect of Distance on the Electrostatic Force

Purpose

In this investigation you will examine sample data from a torsion-balance experiment to determine the relationship between the distance of separation and the electrostatic force.

Materials

The only materials that you will need are the schematic torsion-balance diagrams that are provided for you.



Study the preceding diagram and answer the following questions.

11. What type of force exists between Ball A and Ball B? Note that they are both metal and have similar charges.

12. Will the force be attractive or repulsive? Why?

13. If Ball B is in a fixed position and Ball A is free to rotate, will Ball A rotate clockwise or counterclockwise?

Check your answers by turning to the Appendix, Section 1: Activity 3.

If the arm on the torsion balance rotates, this causes the torsion spring to tighten with a certain force, which is indicated on the scale. Coulomb had predetermined the graduation of the force scale in grains of force, but, in this simplified version, the scale is set in units of force that will be referred to as F units.

Procedure

- Ball B is initially charged negative by touching it to a charged rubber rod that has been rubbed with fur. Although Coulomb did not know how much charge was on Ball B, he called the amount of charge on Ball B q_B.

- Ball B is now touched momentarily to Ball A, which was initially neutral.

14. What happens to Ball A when it is in contact with Ball B?

15. a. If Balls A and B are identical, what is the total charge present on Balls A and B?

    b. What is the charge on each ball?

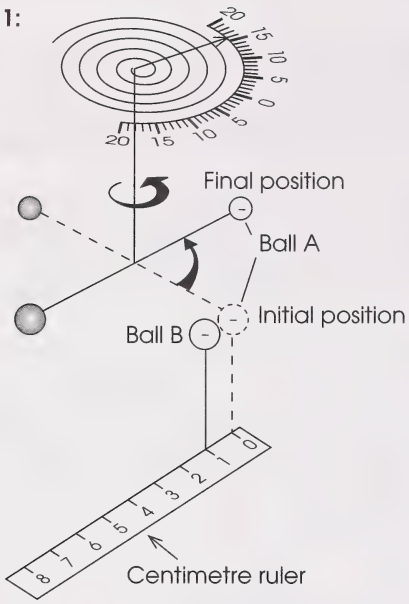
Check your answers by turning to the Appendix, Section 1: Activity 3.

- With Ball A held in place, Ball B is now placed 1.0 cm away. Ball A is then released, allowing it to rotate.

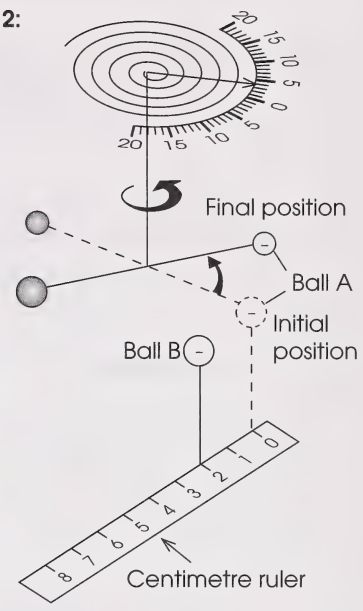
- The F_e repulsion is measured and the procedure is repeated with ball B set at positions 2.0 cm, 4.0 cm, and 8.0 cm. The results of each trial are indicated in the diagrams shown in the Observations section. Note that the angles of rotation have been made large enough for you to make force measurements. In Coulomb's actual apparatus, the angles of rotation were all less than 10°.

Observations

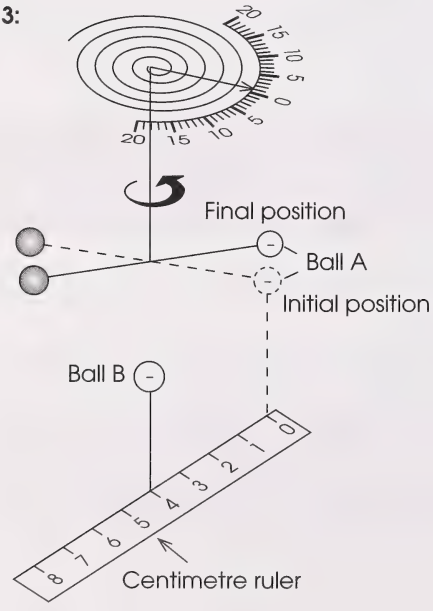
Trial 1:



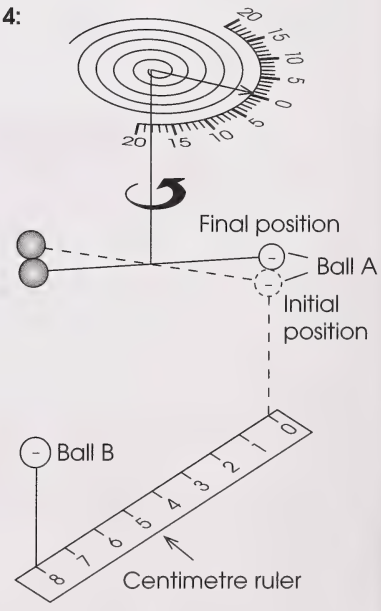
Trial 2:



Trial 3:



Trial 4:



Data

16. Study the diagrams and create a chart of values depicting the force of electrostatic repulsion (F_e) in F units when the distance between the charges (r) is 1.0 cm, 2.0 cm, 4.0 cm, and 8.0 cm.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Analysis and Interpretation

17. Draw a graph of F_e versus r. Use the standard graph paper. Be sure to leave the appropriate number of squares on the horizontal axis and on the vertical axis.

18. Describe the shape of the graph drawn in the preceding question. Explain how this shape suggests an inverse squared relationship between the distance and the electrostatic force.

19. You can verify your answer to the preceding question by completing the following steps.

    a. Create a data chart with columns for distance, $\frac{1}{r^2}$, and F_e. Complete the data chart using the distances and F_e values from the answer to question 16.

    b. Plot a graph of the data with F_e on the vertical axis and $\frac{1}{r^2}$ on the horizontal axis. Use standard graph paper. Leave the appropriate number of squares on each axis.

20. Based on your results, write a mathematical expression describing the relationship between F_e and r. What is this type of relationship called?

21. How does this expression compare with Newton's relationship between F_g and r?

Check your answers by turning to the Appendix, Section 1: Activity 3.

The preceding investigation indicates that Priestley's hunch was right and it also sheds light on some of the behaviour between the charged objects that you observed in this activity.

Why are the repulsive forces between two objects, such as the spheres in the torsion balance, most intense when they are very close together? The inverse-square nature of the electrostatic force provides the answer. If the two charged spheres are only 2 cm apart, they may experience an electrostatic force that you could call F_e. Taking these two spheres and moving them 4 cm apart means that the force is now only $\frac{1}{4}F_e$. Multiplying the distance by 2 has the effect of reducing the force by $\frac{1}{4}$ because the inverse of 2^2 is $\frac{1}{4}$. Using this same line of reasoning, you can show that making the distance four times greater would reduce the force by $\frac{1}{16}$, and that making the distance ten times greater would reduce the force by $\frac{1}{100}$.

In the next investigation you will find out if the charges in Coulomb's law have the same effect on force as the masses in Newton's law of universal gravitation.

Investigation: The Effect of Charge on Electrostatic Force

Purpose

In this investigation you will analyse data collected from a torsion-balance experiment to determine how varying the charge on one ball can influence the electrostatic force between the two balls.

Materials

The only material needed is sample data from a torsion balance-type experiment. This data is provided for you in the investigation.

Background Information

Visions

Although Coulomb had no way of determining the exact amount of charge on an object, he did devise an ingenious method of varying the charge in a controlled way. You can learn more about Coulomb's method by reading the second paragraph on page 238 of your textbook.

22. Explain why touching a charged metal sphere with an identical neutral sphere would give each sphere half of the original amount of charge? Support your answer with a series of diagrams.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Procedure

By varying the charge on Ball B and placing it a known distance from Ball A each time, Coulomb measured the force of repulsion between the two balls by reading the force scale. The following table summarizes his results.

Data

Charge on Ball A (q_A) (q units)	Charge on Ball B (q_B) (q units)	Product of Charges ($q_A q_B$) (q^2 units)	Force of Repulsion (F_e) (F units)
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4} = 0.25$	4
$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8} = 0.125$	2
$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{16} = 0.0625$	1
$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{32} = 0.0313$	$\frac{1}{2}$

Analysis and Interpretation

23. Plot a graph of electrostatic force (F_e) versus the product of the two charges ($q_A q_B$). Use the standard graph paper. Be sure to leave the required number of squares on each axis.

24. Describe the shape of the graph you plotted.

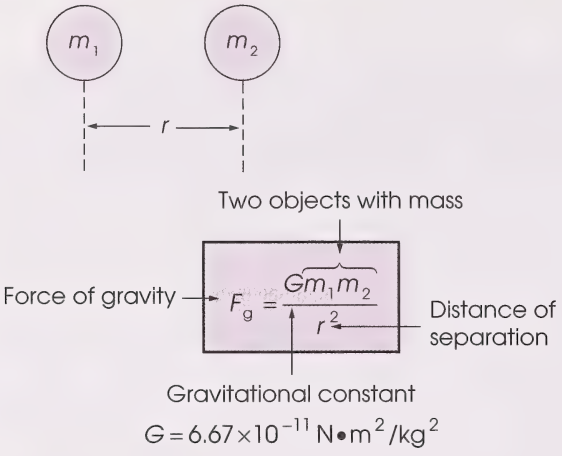
25. Based on the graph, what is the relationship between the electrostatic force and the product of charges?

Check your answers by turning to the Appendix, Section 1: Activity 3.

In this activity you have been using data and techniques similar to those used by Coulomb to determine the equation for electrostatic force. The similarities between the equations for gravitational force and electrostatic force can now be clearly illustrated.

26. Complete the following comparison chart by copying it into your notebook and then filling in the missing information. The constants can be found in the Science 30 Data Booklet which is in Module 1.

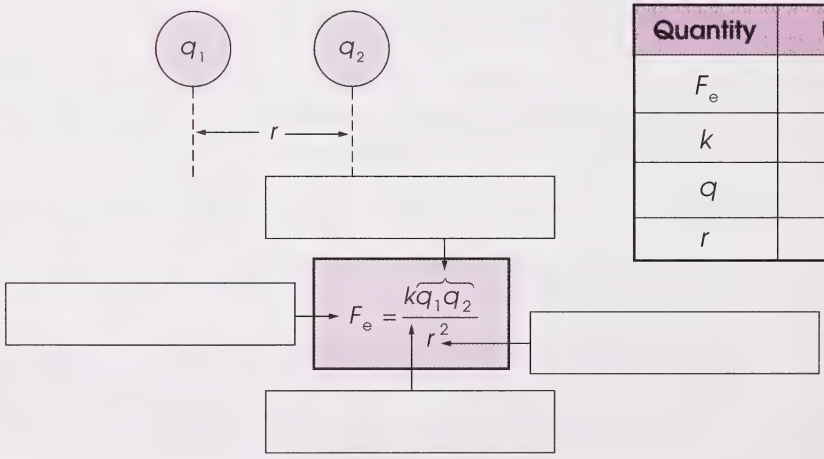
The Law of Universal Gravitation



Quantity	Units
F_g	N
G	$\frac{N \bullet m^2}{kg^2}$
m	kg
r	m

Coulomb's law – the law that describes the electrostatic force between two charged objects

Coulomb's Law



Quantity	Units
F_e	
k	
q	C
r	

coulomb (C) – the unit of charge in the SI system

In honour of the pioneering work done by Coulomb, the equation describing electrostatic force is named Coulomb's law and the unit of charge in the SI system is the **coulomb (C)**. The coulomb is a huge unit of charge. One coulomb is the charge of 6.25×10^{18} electrons. In common terms, a coulomb is the amount of charge delivered by a typical lighting bolt. It is because the coulomb is such a tremendously large amount of charge that the coulomb constant is so large.

27. Imagine the following situation. Two metal globes have both been given a charge of +1.00 C and are separated by 1.00 m.

    a. Calculate the magnitude of the electrostatic force of repulsion between the two globes using Coulomb's law.

    b. Why must this situation only be imagined? Why couldn't you set this up in the laboratory?

Check your answers by turning to the Appendix, Section 1: Activity 3.

It is truly remarkable that two of the most fundamental laws in physics, which describe completely different phenomena and are based on completely different observations, should be so similar. The reason for these similarities remains a mystery to this day. However, it would be wrong to say that these forces are identical, because there are some important differences:

- The force of gravity is always an attractive force.
- The electrostatic force can be attractive or repulsive, depending on the sign of the charges.

Visions

The best way to learn about the use of the electrostatic force is to try some problems. First, study the Example on page 239 in your textbook. Then do the following problems.

28. A Van de Graaff generator is a large electrostatic machine that can create charges of about $+4.5\times10^{-6}$ C on its large metal globe. A balloon with a charge of $+1.5\times10^{-9}$ C is brought in close to the Van de Graaff generator so that their centres are separated by 45 cm.

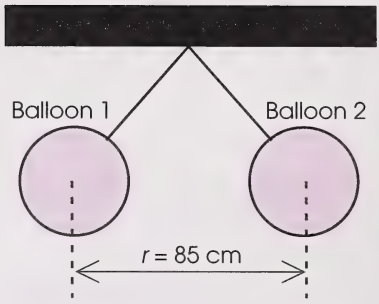
    a. Calculate the magnitude of the electrostatic force.

    b. What is the direction of the electrostatic force on the balloon?

Visions

29. Do Practice Problem 1 on page 240 of your textbook. Hint: The charge on the nucleus will be $27\left(+1.60\times10^{-19}\text{ C}\right)=4.32\times10^{-18}$ C.

Two spherical balloons are estimated to each have a negative charge of 0.3 μC. Use this information to answer questions 30 to 33.



30. If the balloons have their centres separated by 85 cm, calculate the magnitude and direction of the electrostatic force between them.

    (Hint: $0.3\ \mu C = 0.3 \times 10^{-6}\ C = 3 \times 10^{-7}\ C$.)

31. How would you describe the magnitude and direction of the electrostatic force on Balloon 1?

32. How would you describe the magnitude and direction of the electrostatic force on Balloon 2?

33. Which of Newton's laws is illustrated in your answer to the two preceding questions? Explain concisely.

Check your answers by turning to the Appendix, Section 1: Activity 3.

How is it that one charged object can exert a force on another even though they don't touch? This is the same problem of action-at-a-distance that you applied to gravity in Activity 2. In the next activity you will see that the field concept can be applied equally well to the case of electrostatic forces.

Activity 4: Electric Fields

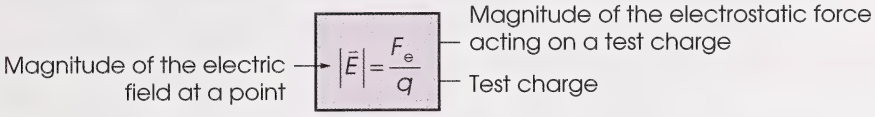
How can Earth hold the moon in orbit even though Earth doesn't touch the moon? A similar question can be asked about electrostatic phenomena: how can a balloon attract strands of your hair even though the balloon may be held at arm's length—not even touching your hair?

electric field – the space surrounding a charge in which other charges will experience an electrostatic force

The same kind of ideas that you've been using with gravitational fields can also be applied to electric phenomena. After all, if a charged balloon can exert a force on the hairs of your head and make them stand on end, even though the balloon does not touch your hair, the balloon must be surrounding itself with an **electric field.**

electric field strength – a vector that indicates the force per unit of a positive test charge

The equation for the magnitude of the **electric field strength** in space can be developed in a way that is very similar to the development of the gravitational field equation.


Magnitude of the electric field at a point
$|\vec{E}| = \frac{F_e}{q}$
Magnitude of the electrostatic force acting on a test charge
Test charge

The symbol for electric field, $|\vec{E}|$, could be confused with the symbol for energy, E. To avoid confusion, the electric field symbol will always be written with a vector arrow on top. When only the magnitude is required, absolute value signs will be used. Since energy is a scalar quantity, it would never be represented with vector notation.

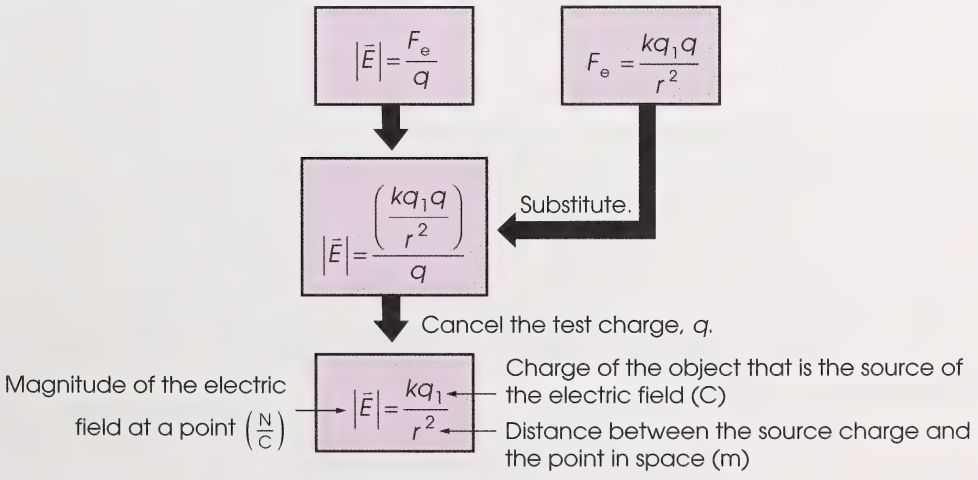
1. Use the electric field equation to determine the units for electric field.

2. A balloon exerts an electrostatic force of 3.5×10^{-4} N on a speck of dust that has a charge of 9.2×10^{-9} C. Calculate the magnitude of the electric field of the balloon at the point in space occupied by the dust speck.

3. If it was possible to place a 1.0-C charge in the position of the dust speck, what is the magnitude of the electrostatic force that the 1.0-C charge would experience?

Check your answers by turning to the Appendix, Section 1: Activity 4.

The magnitude of the electric field can be determined from another equation that is derived from Coulomb's law. Note the similarities to your earlier work with gravitational fields.


$|\vec{E}| = \frac{F_e}{q}$
$F_e = \frac{kq_1q}{r^2}$
Substitute.
$|\vec{E}| = \frac{\left(\frac{kq_1q}{r^2}\right)}{q}$
Cancel the test charge, q.
Magnitude of the electric field at a point $\left(\frac{N}{C}\right)$
$|\vec{E}| = \frac{kq_1}{r^2}$
Charge of the object that is the source of the electric field (C)
Distance between the source charge and the point in space (m)

As was the case with the equations for the gravitational field, the two equations for the magnitude of the electric field required you to be very clear about the meanings of the variables.

$$|\vec{E}| = \frac{F_e}{q}$$ ← This is the charge of the object brought into the electric field. This charge is known as the **test charge**.

$$|\vec{E}| = \frac{kQ}{r^2}$$ ← This is the charge of the object that is producing the electric field. This charge is know as the **source charge**.

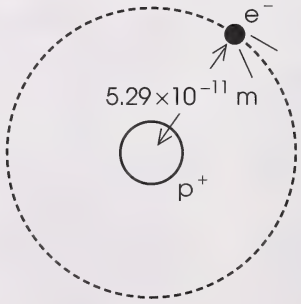
4. Refer to the derivation of the preceding equation to answer these questions.

   a. What two variables influence the magnitude of the electric field of a source charge at a point in space?

   b. What does the Coulomb constant, *k*, indicate about the kind of objects that produce significant electric fields?

5. In another question you found the magnitude of the electric field of a balloon in the position occupied by a dust speck. This calculation could also be done in terms of the charge on the balloon. If the balloon had a charge of 4.8×10^{-7} C, and the point in space occupied by the dust speck was 33.7 cm away, calculate the magnitude of the electric field of the balloon.

6. In a simplified model of the hydrogen atom, a proton is the nucleus and an electron orbits 5.29×10^{-11} m away.



   a. Calculate the magnitude of the electric field at the location occupied by the electron.

   b. Use your answer from question 6. a. to calculate the magnitude of the electrostatic force acting on the electron.

c. Check your answer to question 6. b. using Coulomb's law.

Check your answers by turning to the Appendix, Section 1: Activity 4.

You may have noticed that the initial definitions for electric field include vectors, and yet all the work to this point with electric fields has only involved magnitudes. It's reasonable to wonder why.

The reason is that the direction of an electric field vector is slightly more complicated than the direction of a gravitational field vector. Unlike gravitational effects, electrostatic effects can be both attractive and repulsive, depending on the signs of the charges. Gravitational force is always attractive and directed towards the centre of the source mass, but the electrostatic force can be directed either towards or away from the source charge, depending on the sign of the test charge. How can this be resolved?

The solution is for everyone to agree about the type of test charge that will be used. When you think about it, the test charge really doesn't affect the field—its only purpose is to test the presence of an electric field. Internationally, scientists have agreed that the electric field vector will always have a direction that is the same as the electrostatic force on a positive test charge. The vector versions of the electric field equations can now be written as follows:

- $\vec{E} = \frac{F_e}{q}$ with direction determined by a positive test charge.
- $\vec{E} = \frac{kQ}{r^2}$ with direction determined by a positive test charge.

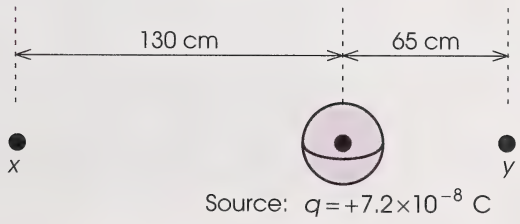
Visions

You can see how to deal with the direction of the electric field vector by studying the two examples on page 241 of your textbook. Once you finish carefully studying the examples, do the following questions:

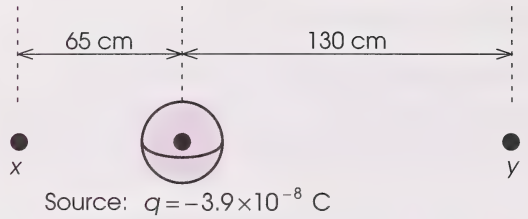
7. Do Practice Problems 1 and 2 found on page 241 of your textbook.

8. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams by calculating and then drawing the electric field vectors for points x and y. When you draw the field vectors, keep the lengths proportional.

a.



b.



9. What can be said about the direction of the electric field around a positive source? Explain.

10. Repeat question 9 for a negative source.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Visions

When drawing electric fields it is important to remember that what you are drawing is the force per unit charge acting on a positive test charge. Keep this idea in mind as you examine page 242 of your textbook. Be sure to pay particularly close attention to the caption under the figure.

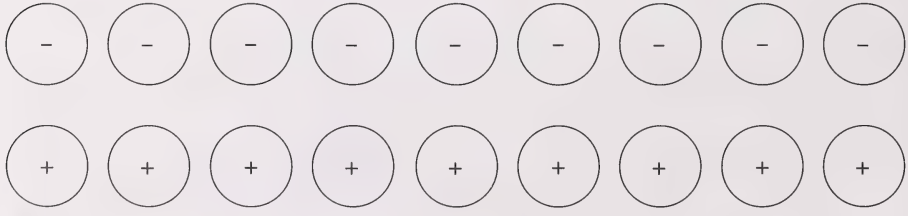
11. Copy the following diagrams into your notebook. Complete the diagrams by drawing the electric field lines between the sources. You will need to leave more space between the diagrams than what is indicated here.

a. (−) (−)

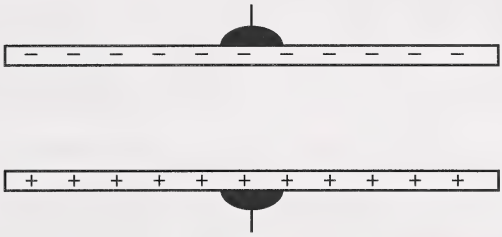
b. (+) (+)

c. (+) (−)

12. The following diagram shows a row of negative charges above a row of positive charges. Copy the diagram into your notebook. Complete the diagram by sketching the electric field in the region between the rows. Explain why you drew the lines the way you did.



13. The following diagram shows two parallel metal plates. The diagram is an edge-on view. The top plate is negatively charged and the bottom plate is positively charged. Copy the diagram into your notebook. Complete the diagram by drawing the shape of the electric field lines in the region between the plates. Explain why you drew the lines the way you did.



Check your answers by turning to the Appendix, Section 1: Activity 4.

In this activity you've seen how electric fields can be described and drawn. In the next activity you will learn how to describe and draw magnetic fields.

Activity 5: Magnetic Forces and Fields

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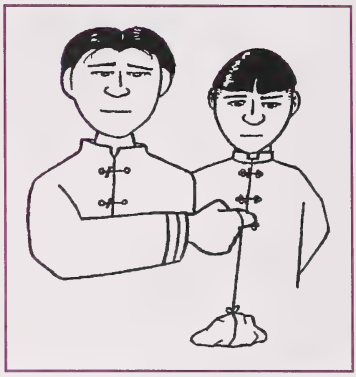
A compass is useful when it is used with a map because it can indicate directions and show the way to your destination. The tiny needle inside the compass is actually a small magnet that aligns itself with the north and south magnetic poles of Earth. Have you ever wondered how a compass needle is deflected even though nothing seems to be touch it?

In previous activities this kind of phenomenon was classified as action at a distance. The outcome of theories developed to explain these events is a field concept. The same approach will be used here.



The knowledge and use of magnetism goes far beyond the discovery of magnetic rocks (iron ore) discovered by the Chinese over 2000 years ago. Another name for magnetic rocks is lodestone. Chunks of these rocks were the first hand-held magnets people could use.

1. What use for magnetic rocks did society have about 2000 years ago?

Some of your previous experiences should tell you that not all substances are magnetic. In this module you will examine why some substances are magnetic and others are not.

2. a. Name one substance that is magnetic.

   b. What do you think makes the substance magnetic?

Check your answers by turning to the Appendix, Section 1: Activity 5.

3. What is the basic energy transformation that occurs in the operation of an electric drill?

Many of the electric devices that you use involve conductors that carry a current that creates a magnetic effect. This magnetic effect interacts with other magnets and causes an energy transformation to occur. Did you know that magnetic particles on videocassettes and audiocassettes are aligned to produce video images and sound? Amazing! There are many more uses of magnetic effects than these basic energy transformations. You will discover that individual moving charges are also affected by magnets. For example, the systems of living organisms function by ion exchange. Therefore, magnetic effects could affect the operation of these systems.

4. What kind of research could be done with organisms living in environments where magnetic effects are particularly strong?

Fairly recent technological developments that use magnetism include electromagnetic impulse devices. These devices generate a changing magnetic field that is used to aid the healing process of injuries. Electromagnetic imaging devices, which provide an image of human tissue, have also been developed. This technology has been useful for imaging abnormal tissues, such as cancerous growths.

Navigation has also come a long way since the Chinese used a suspended piece of lodestone over 2000 years ago. Today, global positioning satellite systems (GPS) use electromagnetic waves generated by accelerating charges to give the precise location of objects on Earth.

5. a. Why is it important to study and understand concepts of magnetism?

   b. List four uses of magnetism.

Check your answers by turning to the Appendix, Section 1: Activity 5.

In the next investigation you will observe and record the behaviour of magnetic phenomenon.

Science Skills
- ☐ A. Initiating
- ☑ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Investigation: Properties of Bar Magnets

Purpose

In this investigation you will explore the regions of magnetic influence surrounding permanent bar magnets.

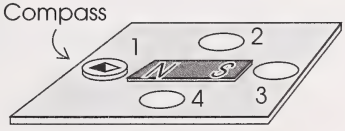
Materials

For this investigation you will need the following materials:

- two bar magnets
- a small magnetic compass
- iron filings
- a sheet of paper or a glass plate that measures approximately 20 cm × 28 cm

Procedure and Observations

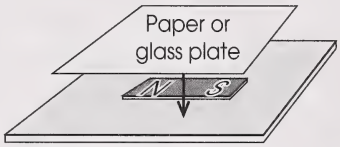
- Place the bar magnet on a flat surface.
- Bring the compass near the north pole, as shown by position 1 in the diagram. Observe the direction in which the north pole of the compass points.



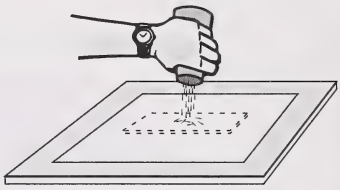
- Place the compass at positions 2, 3, and 4.

6. Copy the preceding diagram into your notebook and indicate the direction in which the north pole of the compass points at positions 1, 2, 3, and 4.

- Place the bar magnet on a table or flat surface. Then place the paper or glass plate over the magnet.



- Gently sprinkle iron filings on the glass plate or paper. Be sure to work neatly because iron filings are difficult to remove from the magnet and they can permanently stain clothing.



magnetic field – the region surrounding a bar magnet in which a magnetic force exists

magnetic field lines – lines along which a magnetic force exists within a magnetic field

magnetic flux – density of magnetic field lines in a given space or area

7. Sketch the pattern of iron filings that you observe around the bar magnet.

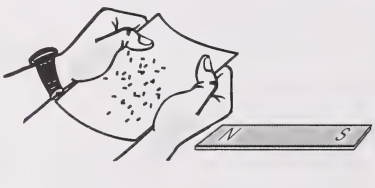
The alignment of the iron filings around the magnet can be described in terms of a **magnetic field**. The symbol for magnetic field is $\vec{B}$. The presence of the magnetic field around the magnet was shown with the iron filings. The distinct lines along which the iron filings align themselves are called **magnetic field lines**.

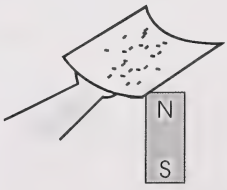
8. Do the field lines overlap? Support your answer by explaining your observations of the iron filings on the piece of paper.

The number of magnetic field lines passing through a given area is called **magnetic flux**. The magnetic flux per unit area is proportional to field strength.

9. Where is the magnetic flux the greatest around the bar magnet? Support your answer.

- Gently lift the paper off the bar magnet and slide the paper with iron filings onto the palm of your left hand. Be careful not to make a mess with the filings. Pick up the bar magnet with your right hand and place the north pole under the piece of paper. Observe the iron filings on the paper.



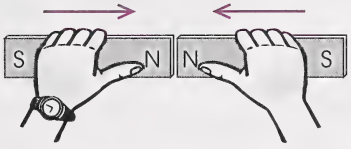


10. What happened when you placed the north pole of the magnet under the paper?

11. Does the magnetic field appear to be two-dimensional or three-dimensional? Support your answer with your observations.

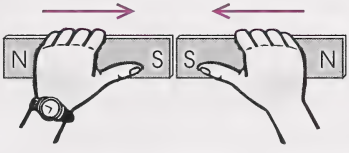
- Return the iron filings to the container. If you put a crease in the paper you will be able to pour the filings into the container without spilling them.

- Hold one bar magnet in each hand and move the two north poles towards each other.



12. Describe the feeling when the two north poles are moved towards each other.

- Turn the magnets around and move the two south poles towards each other.

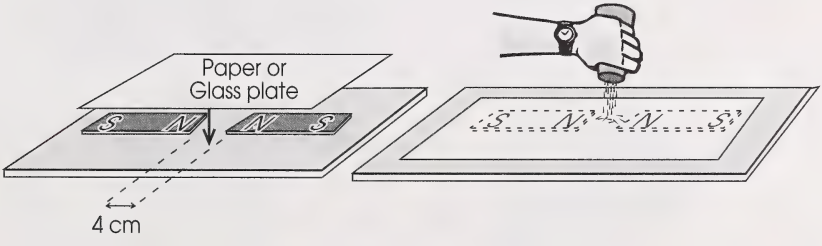


13. Describe the feeling when the two south poles are moved towards each other.

magnetic force – a force that exists within a magnetic field

Since the magnets can exert a **magnetic force** on each other without touching, there must be a field present.

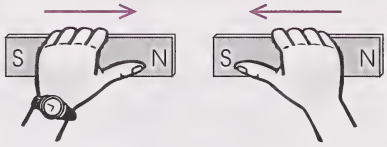
- Place the two bar magnets on a flat surface with the north pole of one magnet about 4.0 cm from the north pole of the second magnet. Place the paper or glass plate over the magnets. Gently sprinkle iron fillings on the glass plate or paper.



14. Sketch the pattern of iron filings between the ends of the bar magnets on a diagram in your notebook.

    - Return the iron filings to the container. If you put a crease in the paper, you will be able to pour the filings into the container without spilling them.

    - Hold one bar magnet in each hand and move the north pole of one magnet towards the south pole of the second magnet.



15. Describe the feeling when the north and south poles of these magnets are moved towards each other.

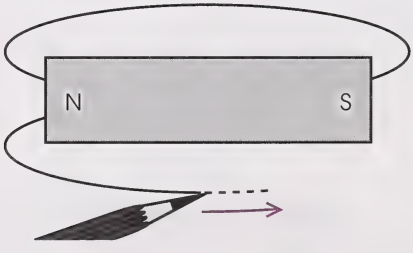
16. Describe the two types of magnetic forces that you have experienced.

    - Place the north pole of one magnet about 4 cm from the south pole of a second magnet. Place a sheet of paper or glass over them. Sprinkle iron filings over the ends of the magnets.

17. Sketch the pattern of iron filings between the ends of the bar magnets and write a brief description of your observations.

    - Trace the outline of one bar magnet in your notebook. Leave some space around it. Label the north and south poles of the magnet.

    - Draw one arc above the outline of the magnet and one arc below it. These arcs should look similar to the patterns made by the iron filings.



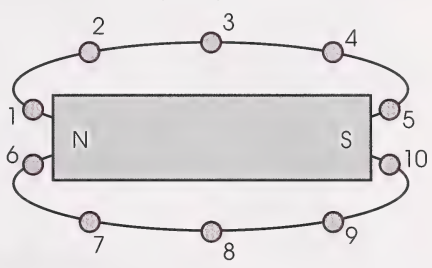
    - Place the bar magnet over its traced outline.

Magnetic fields are vector fields much like gravitational and electric fields. The direction of a magnetic field is defined in terms of the direction of the north pole of a compass placed in a magnetic field.

- Place the compass near the north pole of the bar magnet. Note: The magnet should still be positioned over its outline in your notebook.

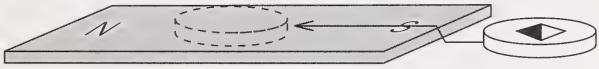
18. In which direction does the north pole of the compass point when placed near the north pole of the bar magnet?

- Slowly move the compass along the magnetic field line arc from position 1 to position 5. Then place the compass in position 6 and move it through to position 10.



19. Sketch the direction of the magnetic field lines for positions 1 to 10. You can do this by drawing an arrow to indicate the direction of the north pole of the compass in each of these positions.

- Now place the compass near the south pole of the bar magnet. Slowly move the compass up over the south pole of the magnet and place it on the centre of the magnet.



20. Record the direction that the north pole of the compass points when placed on the centre of the magnet.

Nicole, did you know that the magnetic field lines are continuous closed curves?
Yes, Jerry. These magnetic field lines must be very concentrated within the magnet.

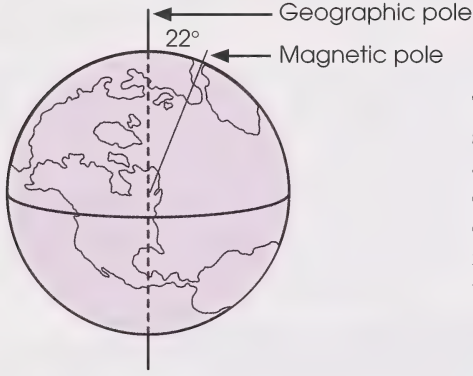
21. Draw a diagram that summarizes the directions of the magnetic field lines inside and outside a bar magnet.

Check your answers by turning to the Appendix, Section 1: Activity 5.

Analysis and Interpretation

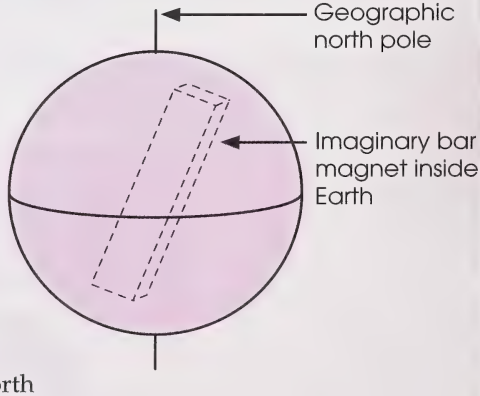
22. How does the alignment of the iron filings around the bar magnet compare with the alignment of the compass needle as the compass is moved around the magnet?

23. Is a net force acting on the compass needle when the compass needle is aligned along a field line? Provide evidence. Are there any forces acting on it?



The magnetic field surrounding Earth is similar to a magnetic field that surrounds a bar magnet. If you were orienteering in central Alberta, the north pole of your compass would align along a magnetic field line that is (on average) 22° east of the north geographic pole.

24. Copy the diagram to the right into your notebook and complete it by drawing in the field lines, labelling the direction of the field lines, and labelling the poles of the imaginary bar magnet inside Earth's magnetic field.



25. What is odd about the diagram that you drew to answer the preceding question? When most people talk about the north pole, are they referring to the geographic north pole or the magnetic north pole?

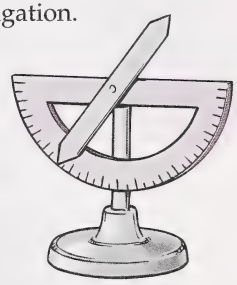
Check your answers by turning to the Appendix, Section 1: Activity 5.

The Magnetic Field and Life on Earth

To this point most of your learning experiences with magnetic fields have been related to a hands-on investigation of objects in magnetic fields. Now that you have a sense of how objects behave in magnetic fields, you can consider how magnetic fields influence life for humans and other organisms.

Visions

Read from the middle of page 248 to the end of the first paragraph on page 250 of your textbook to discover how people have used magnetic fields for navigation.



26. What is the origin of the word *lodestone*?

27. Describe the differences between magnetic declination and magnetic inclination. Hint: Magnetic declination is measured with a compass and magnetic inclination is measured with a dipping needle.

Visions

It's quite interesting to know that a wide variety of animal species also use magnetic field lines for navigation purposes. You can learn more about this by reading from the second paragraph on page 250 to the middle of page 251.

28. Describe what would happen to Australian mud bacteria if they were transplanted to Canada.

29. Explain why a homing pigeon, used to flying with a gradient on one side, would fly in circles if it took off from the middle of a magnetic depression.

30. Describe how whales navigate 10 000 km without getting lost.

Visions

The magnetic field of Earth not only provides valuable navigation aids for species on Earth, it also protects most life on Earth from radiations from space. You can discover how Earth's magnetic field shields us by reading from the middle of page 251 to the bottom of page 252 in your textbook.

31. Make some specific predictions about how your life would change if Earth's magnetic field disappeared.

Check your answers by turning to the Appendix, Section 1: Activity 5.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

In this section you have seen three examples of how the field concept can be used to solve the perplexing problem of forces acting at a distance. Gravitational fields, electric fields, and magnetic fields all enable forces to act on objects with no apparent physical connection between the source and the test object.

You can get a good overview of the main ideas and significant applications by reading the summary on pages 253 and 254 of your textbook. As you read, focus on the headings in the following summary chart.

1. Copy the following headings into your notebook. Be careful to adjust the space under each heading to accommodate your answers. Complete the chart by writing summary points comparing gravitational, electric, and magnetic fields.

Characteristic of Field	Gravitational	Electric	Magnetic
What is the source or origin of this field?			a moving charge
What determines the direction of this field?	the direction of the gravitational force on a test mass		
Can this field exert both attractive and repulsive forces?		attractive and repulsive	
How does the force exerted by the field change as the distance from the source increases?			decreases
How can this field be sketched? (Provide examples of each.)			

2. Earth's Magnetic Field

The video series called *Electromagnetism* contains a ten-minute program called "Earth's Magnetic Field." This video is available through the Learning Resources Distributing Centre or may be obtained through your local school or library. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

a. When a piece of lodestone was suspended with a string, what was the result and what advancements were made using this new form of navigation?

b. French scientist Pedros Peregritris chiselled a piece of lodestone into a sphere and then sprinkled iron filings around it. How did the iron filings align on the sphere?

c. Compare the arrangement of iron filings around a bar magnet here on Earth and the iron filing pattern around a bar magnet in space. Explain the difference in the patterns.

d. William Gilbert concluded that Earth is a huge bar magnet. On what basis did he conclude that the south magnetic pole is in the northern hemisphere?

e. Describe the result of heating a bar magnet.

f. What is believed to be the source of Earth's magnetic field?

g. Define the term *magnetic declination* that is mentioned in the video.

h. What is the magnetic declination in Toronto?

i. The magnetic field for a particular location is oriented with respect to Earth's surface. At what point on Earth's surface would the magnetic field line be parallel to Earth's surface?

j. What is the term given to the angle between Earth's surface and the field lines when the field lines cross the surface?

k. Describe the use of a dip needle. How would it be positioned over the north magnetic pole?

l. Explain why compass navigation in the Arctic would not be very accurate. Suggest other means of navigation.

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

1. Do the following investigation.

Science Skills
- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [ ] F. Evaluating

Investigation: Plants in Circular Motion

Purpose

In this activity you will investigate the effects of circular motion on the direction of shoot and root growth from bean seeds.

Materials

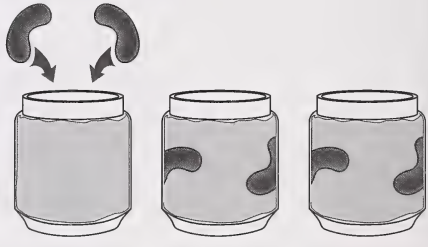
You will need the following materials for this investigation:

- an old record player with a 78 r/min speed
- three identical small glass jars
- an old long-play phonograph record
- a large cardboard box
- six bean seeds
- paper towel
- epoxy glue

You will need to find an old record and record player for this investigation. The record and record player may be ruined by the end of this experiment.

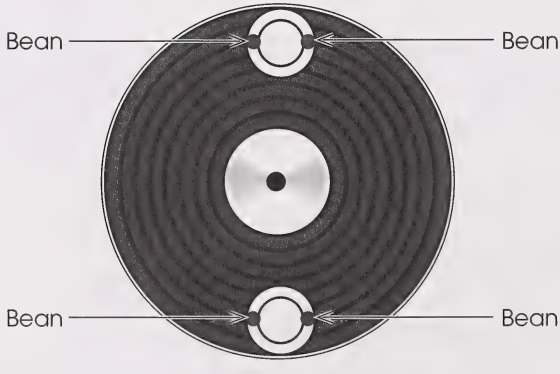
Procedure

- Fill the jars with paper towel.



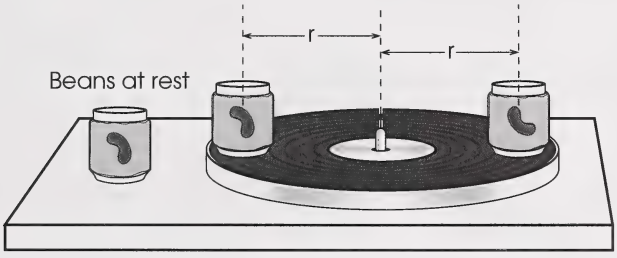
- Place the bean seeds on opposite sides of the jar. Add enough water to soak the paper towel.

- Carefully glue two jars onto the record with the epoxy. Be sure to align the jars so that they are exactly opposite each other on the record and so that the beans are positioned as shown.



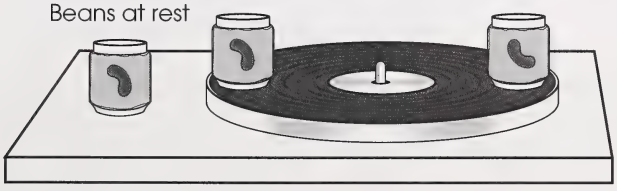
- When the epoxy glue has dried, place the record on the record player. Place the third jar next to the record player.
- Turn the record player on and adjust the speed to 78 r/min.
- Place the large box over the whole apparatus. Be sure to allow air to enter and leave the box so that the record player does not overheat.
- Wait two weeks. You will need to add water to the jars every few days. This will also give you a chance to check the growth of the beans.
- While you are waiting, research the topic of geotropism in a biology textbook. Note that the bean seed is in a rotating reference frame where an imaginary centrifugal force could be observed.

a. Predict which way the roots and stems of the beans will grow. Sketch your predictions on the following diagram.



Observations

b. After two weeks, sketch on the following diagram the way that the bean stems and roots grew.



Conclusions

c. What is the effect of the rotating frame of reference on the stems and roots? Use what you learned about geotropism to answer.

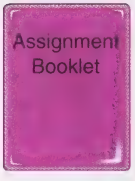
2. Do questions 11, and 12 from the Know section and questions 1, 6, and 7 from the Think section on pages 255 and 256 of *Visions 3*.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In the introduction to this section you were presented with a scenario in which "invisible hands" seemed to reach out and exert forces on objects. You should now understand that fields provide the invisible connection between these objects. The gravitational field, electric field, and magnetic field can all be described in a way that allows for the behaviour of test objects to be predicted.

In the next section you will extend the electric field concept to applications that include electronic test instruments and simple circuits.



ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Using Electric Energy

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Anyone who has bought a small personal cassette player or a motorized toy has read these familiar words on the front of the package: **Batteries Not Included**. Without batteries, these devices are no more than lumps of plastic with wires inside. Why are batteries so essential? What do they provide for these machines? Are the batteries full of extra electrons? Or do the batteries act like tiny generators?

Of course batteries are not the whole story—devices powered by batteries include tiny components connected to form a multitude of circuits. The simplest of these circuits could be described by measurements taken in terms of volts, amperes, ohms, and watts. What do these units mean and what exactly is it that they measure?

In this section you will be introduced to the fundamental quantities and units that describe electric circuits and you will integrate these concepts into the main ideas that run through the whole module. You will then apply what you've learned as you build simple circuits and test them with electronic instruments. The section ends with the investigation of the properties of series and parallel circuits and the application of these properties to household circuitry.

Activity 1: Describing Circuits

How important is electricity to your daily existence? Do you think that your daily routine would change very much if electrical technology was not yet invented? You can gain insight into some of the possible answers to these questions by reading the Introduction to Chapter 8 that can be found on pages 258 and 259 of your textbook.

1. Provide at least three examples of electrical technology that are used by people on a daily basis.

2. Concisely explain the link between your earlier work with electric fields and your upcoming work with electrons moving around electric circuits.

Check your answers by turning to the Appendix, Section 2: Activity 1.

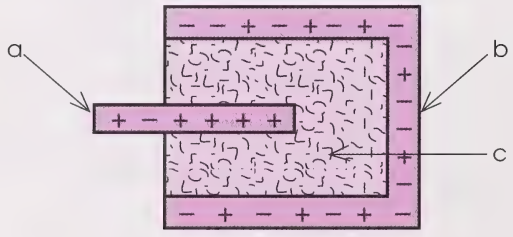
To begin a study of electric circuits requires that you learn some basic terms and definitions. You'll find that many of these ideas connect quite closely to things that you've learned in previous courses.

A good place to start is with a video that uses computer animation to help you visualize what goes on in a simple circuit.

The video series *Electricity* contains a ten-minute program called "Current Electricity." This video may be obtained through your school or local library or purchased from the Learning Resources Distributing Centre. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. Note that you may have to periodically stop the tape in order to record your answers.

3. Explain why two oppositely charged metal spheres are not a good source of charge flow or current.

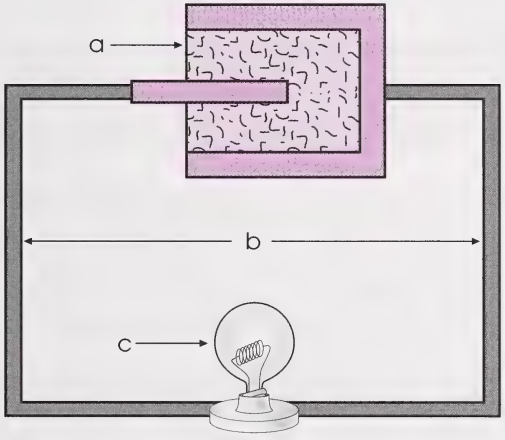
4. Label the following diagram of a flashlight battery and describe the function of each part.



5. What advantages does the flashlight battery have over the oppositely charged metal spheres as a source of current?

6. What is the name given to the continuous flow of charge?

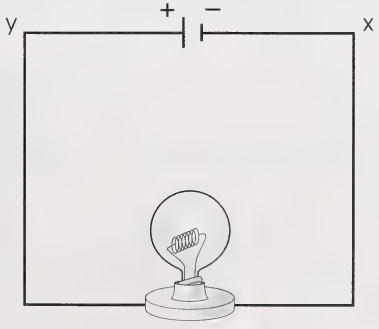
7. Label the following diagram of a simple circuit by describing the function of each part.



8. Draw a simple flow chart to illustrate the energy conversions that occur within a simple circuit.

9. Briefly describe the difference between direct current and alternating current. Provide an example of where each is used.

10. Consider the simple circuit shown. Is there a difference in the number of electrons passing points x and y? Explain concisely.



11. Concisely describe each of the variables in the following equation.

$$I = \frac{q}{t}$$

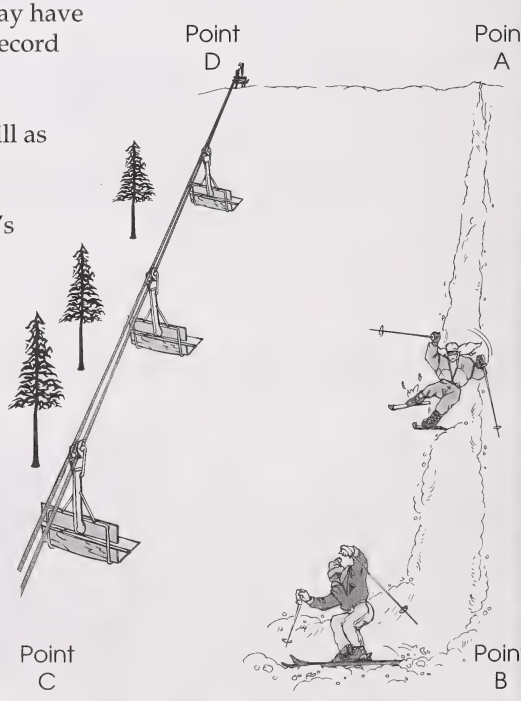
12. Refer to the equation given in the preceding question to write an equation that describes the unit for current.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Now that you've had a chance to think about how an electric current travels around a circuit, it's a good idea to take a closer look at the source of energy for the circuit. If you've ever had batteries wear out, then you know that without a source of energy no electric current is possible. The next video program will help you to understand the role of a battery in an electric circuit by comparing an electric circuit to a ski hill.

The video series *Electricity* contains a ten-minute program called "Potential Difference." This video may be purchased from the Learning Resources Distributing Centre or may be obtained through your local school or library. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. Note that you may have to periodically stop the tape in order to record your answers.

Refer to the following diagram of a ski hill as you answer questions 13 to 17.



13. Between which two points is a skier's gravitational energy increasing? Where does this increase in energy come from?

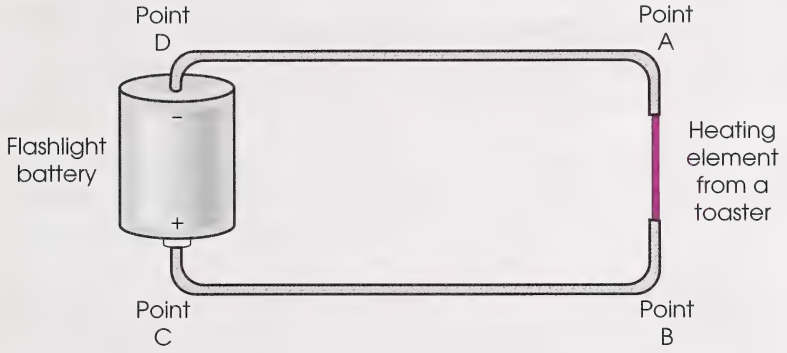
14. At which point(s) does the skier have the most gravitational potential energy?

15. At which point(s) does the skier have the least gravitational potential energy?

16. Describe the energy transitions that occur as the skier travels from Point A to Point B.

17. Use a simple flow chart to describe the total energy transformation occurring on the ski hill.

Refer to the following diagram as you answer questions 18 to 29.



18. What part of the circuit corresponds to the ski lift?

19. What part of the circuit corresponds to the ski slope?

20. What part of the circuit corresponds to the skiers?

21. Between which two points is a coulomb's electric potential energy increased? Where does this increase in energy come from?

22. At which point(s) does a coulomb have the most electric potential energy?

23. At which point(s) does a coulomb have the least electric potential energy?

24. Describe the energy transitions that occur as a coulomb passes from Point A to Point B.

25. Use a flow chart to describe the total energy transformations occurring in the circuit.

26. Concisely describe each of the variables and the corresponding units for the following equation:

$$V = \frac{E}{q}$$

27. Across which points in the circuit is there no potential difference?

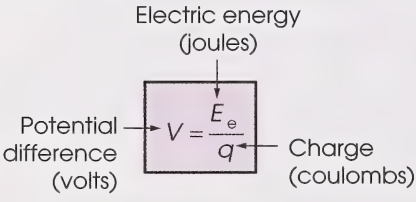
28. Across which points in the circuit does the potential difference decrease?

29. Across which points in the circuit does the potential difference increase?

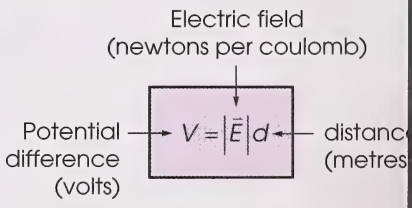
Check your answers by turning to the Appendix, Section 2: Activity 1.

It's worth noting that the reason that potential difference is used so frequently when describing electric circuits is that it is so easy to measure. In fact, it's so easy to measure that it's often used as a way to indirectly determine the electric field strength (which is very difficult to measure) in some circumstances. This does create a potential problem, however, in that it's easy to mix up the symbol for electric field with the symbol for electric energy. One way to keep these ideas distinct is to use a subscript only with the symbol for electric energy, and to reserve vector notation for the electric field. The following equations illustrate this idea.

Equation for Electric Energy



Equation for Electric Field Strengt



Visions

Although the equation shown on the right is new, it's not really that complicated. If you're interested in its origins you can refer to one of the Enrichment activities at the end of this section. You can see how the textbook presents these equations by reading from the top of page 260 to the middle of page 262. Be sure to pay particularly close attention to the Example as the questions that follow involve similar skills.

30. Examine Figure 8.2 on page 260 of your textbook. Suppose the particle was a dust speck with a mass of 7.95×10^{-5} kg and a charge of $+5.2 \times 10^{-6}$ C. Consider the plates were separated by 10.5 cm and maintained an electric field of $3.85 \times 10^{3} \frac{N}{C}$ between them.

    a. Calculate the potential difference that must exist across the charged plates.

b. Calculate the energy that would be given to the dust speck as it travelled from the positive plate to the negative plate. Note that you'll have to rearrange the equation $V = \frac{E_e}{q}$ into the form $E_e = Vq$ to solve this question.

c. If all the energy given to the dust speck was kinetic energy, then how fast would it be travelling the instant before it strikes the negative plate? Note that you will have to rearrange the equation $E_k = \frac{1}{2}mv^2$ into the form $v = \sqrt{\frac{2E_k}{m}}$ to solve this question.

Visions

31. Using the suggestions given in the preceding question as a guide, do Practice Problems 1, 2, and 3 found on page 262 of your textbook. Note that the mass of one electron is 9.11×10^{-31} kg.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Activity 2: Testing Circuits

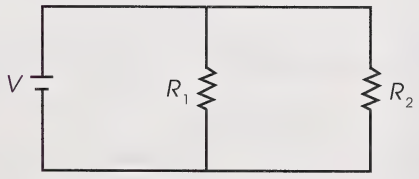
Visions

In the last activity you learned the essential terminology and concepts that describe an electric circuit. In this activity you will explore the relationships between those concepts by building and testing your own circuit. Before getting into the specifics of using the equipment, it's a good idea to review some of the key ideas that you'll be using. Read from the middle of page 262 to the middle of page 263 in your textbook.

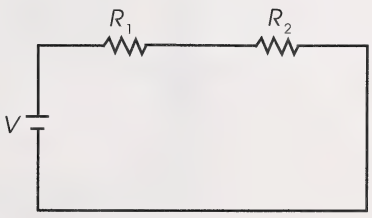
1. If an electric field is established within a conductor, will the electrons move in the same direction as the electric field? Explain your answer.

2. The following schematic diagrams show two resistors connected to a battery. Note that the circuit symbol for a resistor is —WW—, while the variable is *R*.

Circuit A



Circuit B



a. Which circuit shows two resistors connected in series? Concisely explain your answer.

b. Which circuit shows two resistors connected in parallel? Concisely explain your answer.

3. Explain why a resistor is appropriately named.

Check your answers by turning to the Appendix, Section 2: Activity 2.

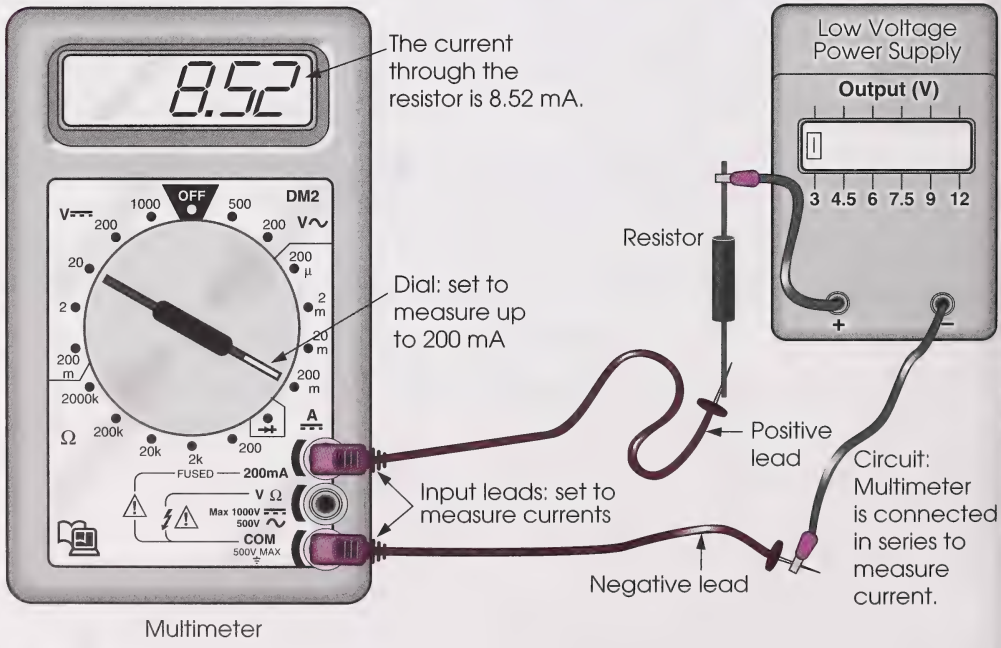
Depending upon the equipment that's available, you could use an ammeter to measure current and a voltmeter to measure potential difference. Alternatively, you could use one device to measure both quantities.

multimeter – a device that can measure a wide range of voltages, currents, and resistances in an electric circuit

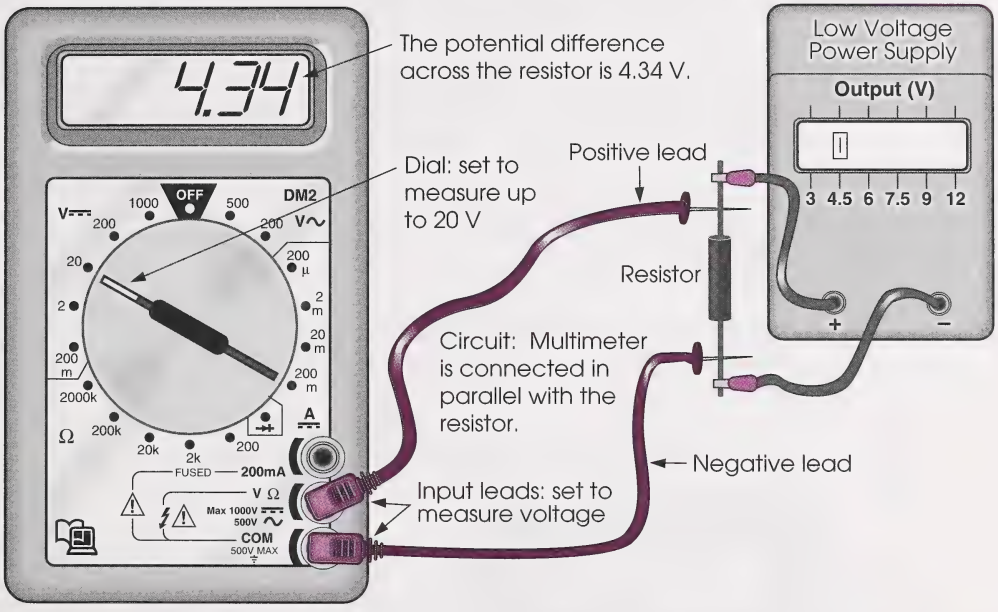
Such a device is called a **multimeter** because it is capable of measuring a number of different quantities. Most multimeters can measure both current and potential difference, so it is likely that this is what you will use for the next investigation.

The following diagrams show a typical multimeter being used to measure current and potential difference. (Your power supply leads may be different than the one shown in the following diagram.)

This shows how to correctly measure **current** with a multimeter.



This shows how to correctly measure **potential difference** with a multimeter.



Multimeter

Note that the negative lead is plugged into the input marked COM, which is an abbreviation for *common*. This refers to the ground (zero potential) that is common to all circuits. The positive lead is plugged into the input for measuring either mA or V. Traditionally, the negative lead is the black one and the positive lead is the red one.

Unfortunately, the cost-effectiveness and convenience of one machine that does everything does have its drawbacks. You have to be very careful that you know what you are measuring and that the following three things are properly adjusted:

- The dial on the meter is set to measure what you want.
- The input leads of the meter are input to measure what you want.
- The circuit has the meter in either series or parallel to measure what you want.

If you forget one of these details, you may blow a fuse in the multimeter. If you are working in a science lab, ask an instructor to check your first attempts using the meter. If you are not working in a science lab, be sure to have a few fuses handy! The following questions are designed to help you be more successful when you start using the multimeter.

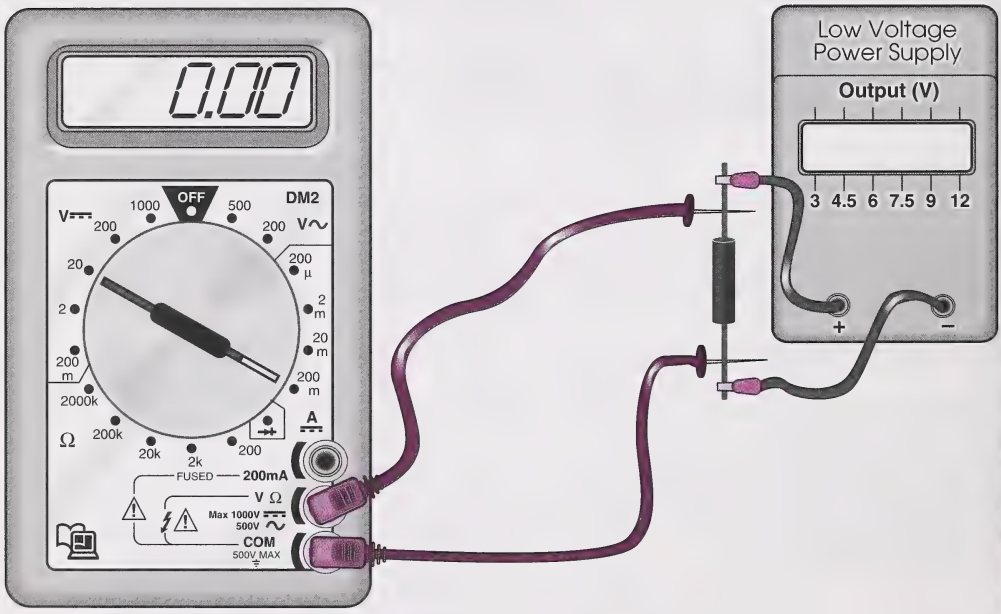
4. Draw a schematic diagram of the multimeter when it is set to measure current through the resistor. In this case the multimeter is acting like an ammeter. Note that the symbol for an ammeter is —(A)—.

5. Draw a schematic diagram of the multimeter when it is set to measure potential difference through the resistor. In this case the multimeter is acting like a voltmeter. Note that the symbol for a voltmeter is —(V)—.

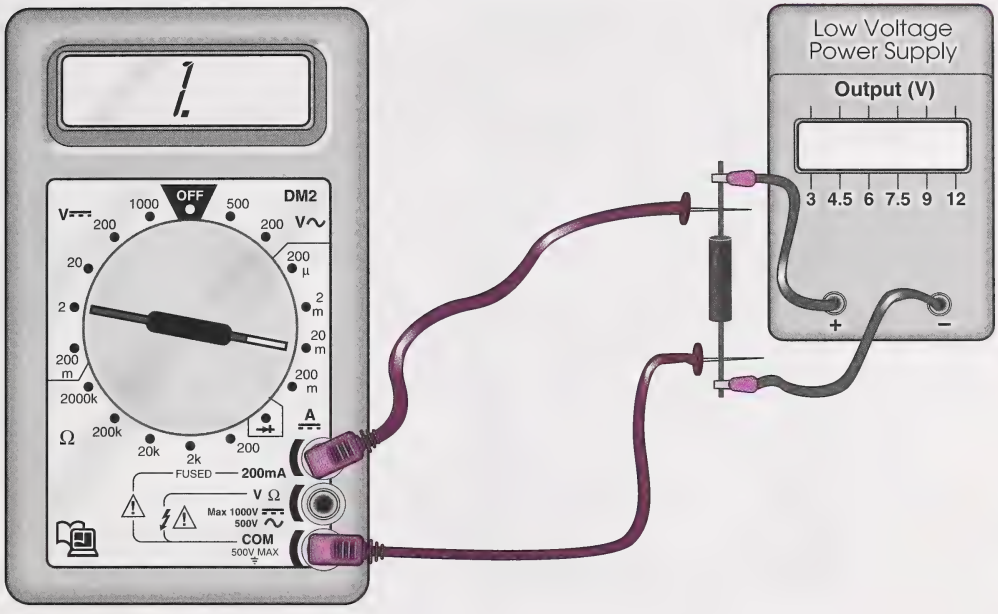
6. Refer to the previous diagram. If the sliding knob on the power supply says 4.5 V, should you use 4.5 V or 4.34 V for the value for potential difference across the resistor? Explain.

7. The following diagrams show typical errors made while using a multimeter. Write a description of the changes that must be made to each setup to make the desired measurement.

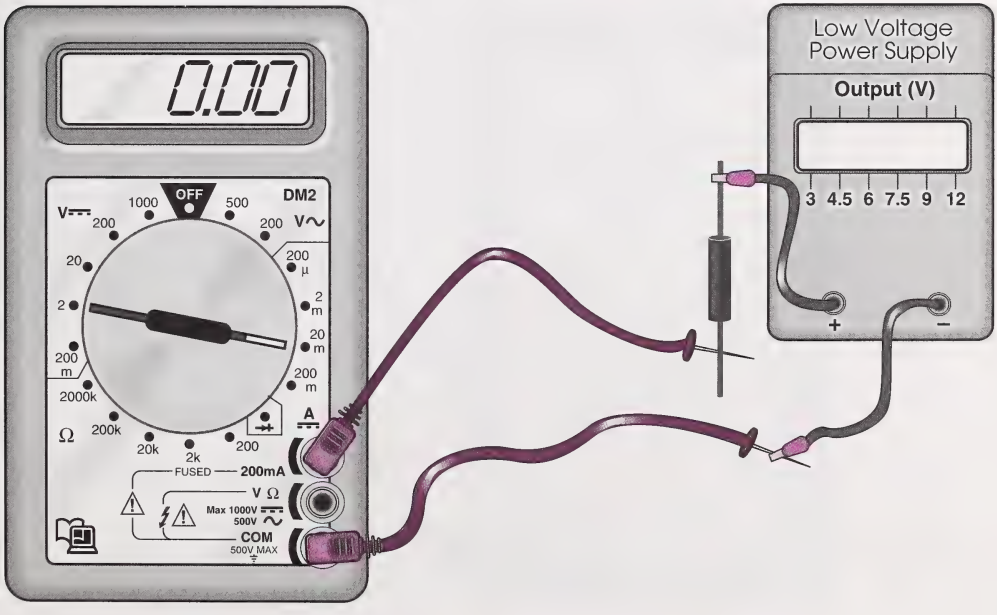
   a. This shows an **incorrect** attempt to measure current.



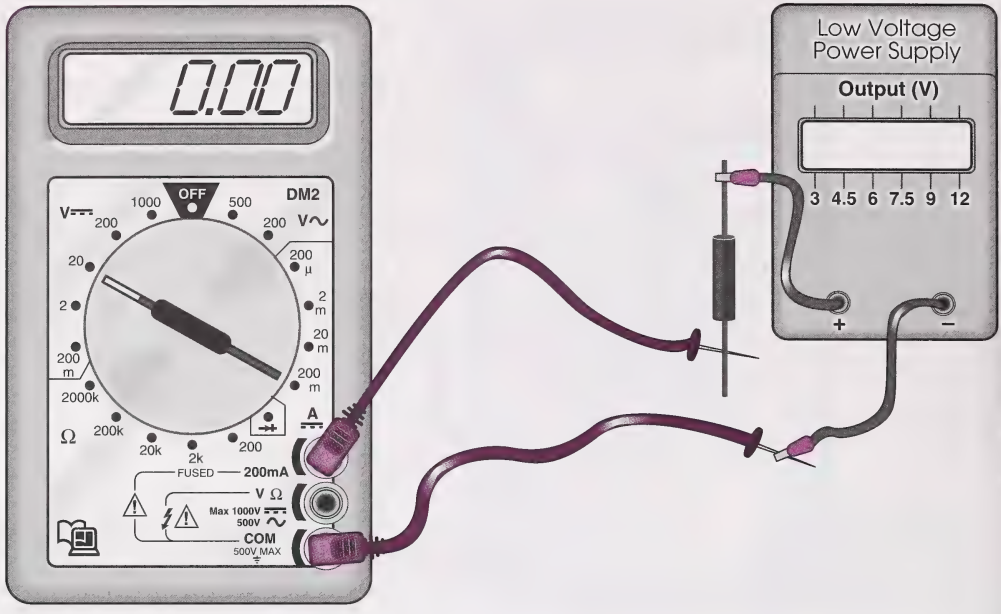
b. This shows an **incorrect** attempt to measure current.



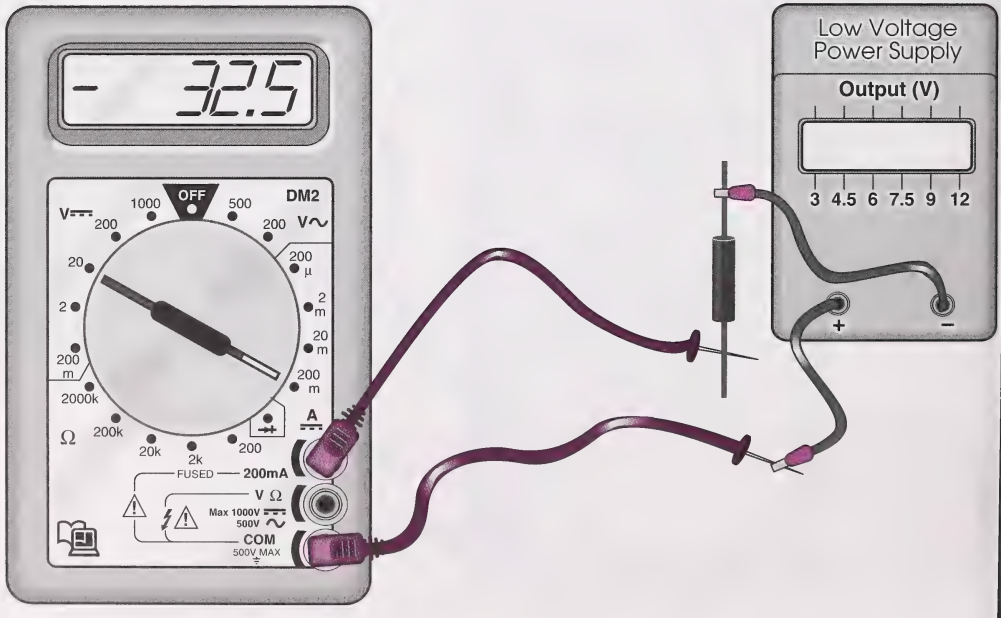
c. Although this circuit is correctly set up to measure current, the meter won't produce a reading other than zero on any range. What is happening here?



d. This shows an **incorrect** attempt to measure potential difference.



e. This attempt to measure current is producing a negative output. What is happening here?



8. What are the three things that you should always double check on your multimeter before you attempt to make a measurement?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The things you have learned so far in this activity will be useful in the upcoming investigation. Keep the diagrams of the multimeter handy because they will be a valuable reference tool whenever you set up a circuit.

Investigation: Measuring Potential Difference and Current for a Resistor

Purpose

In this investigation you will determine the relationship between the voltage and the current for different resistors.

Materials

You will need the following materials for this investigation:

- a multimeter (or an ammeter and a voltmeter)
- a DC power supply capable of producing at least six different output voltages
- three resistors that are rated at 0.5 W

  The resistors should have the following patterns of stripes:

  R_1 – brown, black, red, gold
  R_2 – brown, green, red, gold
  R_3 – red, black, red, gold

- four test leads with alligator clips at each end
- a power outlet into which you can plug your power supply

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch objects such as metal pipes, electric outlets, and light fixtures, that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.

- Only replace the fuse inside the meter with the specified or approved equivalent fuse.

- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock. Even measuring the current of the power supply directly (without a resistor) may burn out the fuse in the multimeter.

- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure and Observations

9. • Read through the entire Procedure and Observations section before you begin. You will be asked to fill in data charts as you do the procedure.

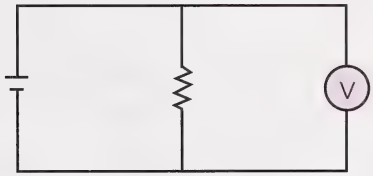
- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers.

Resistor 1	
V (volts)	I $(\times 10^{-3}\ \text{A})$

Resistor 2	
V (volts)	I $(\times 10^{-3}\ \text{A})$

Resistor 3	
V (volts)	I $(\times 10^{-3}\ \text{A})$

- Without turning on the low-voltage power supply, build the circuit as shown in the following photograph and schematic diagram. Be sure to use R_1. In the power supply with a universal adaptor, the tip of the probes without the hole in the tip is positive. The outside of all four probes back of the black ring is negative. Your power supply may also have a 9-volt battery connection. You can use the positive and negative on this connection as well. Your power supply may not have all these adaptors. What you want is a positive terminal and a negative terminal.



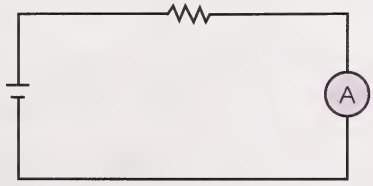
- Inspect your circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected parallel with the resistor.

- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous activity.

- Adjust the knob on the power supply to provide an output of about 3 V and turn on the supply.

- The multimeter should now be reading the potential difference across the resistor. Record this value on the data chart. Don't be surprised if the value indicated by the meter is different than the setting indicated by the knob on the power supply. The value indicated by the power supply knob is only approximate.

- Without changing the setting on the power supply, turn off the power supply and disconnect the multimeter from the circuit. Reset the dial on the meter and the position of the input leads to measure milliamperes. Reconnect the meter as shown in the following photograph and schematic diagram.



- Inspect your circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected in series with the resistor.

- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous activity.

- Turn on the power supply once again. The setting on the power supply should not have changed from the preceding step.

- The multimeter should now be reading the current through the resistor. Record this value on the data chart.

- Repeat the preceding steps at least five more times, each time with a slightly higher potential difference setting on the power supply. **Do not** exceed 20 V. Record your values for potential difference and current on the data chart.

- Repeat the entire procedure for R_2. Record the data on the appropriate chart.

- Repeat the entire procedure for R_3. Record the data on the appropriate chart.

Graphing

10. a. Plot the data of potential difference versus current for R_1. Even though potential difference is actually the manipulated variable, plot it on the y-axis and plot current on the x-axis, as this will make the analysis that follows easier. Use standard graph paper.

    b. Draw the best-fit straight line for the points very carefully. Label the line Resistor 1.

    c. Calculate the slope of the best-fit line. Pick two points on the line of best fit and find the slope using these points.

11. Repeat all the parts of question 10 using the data for R_2. Plot the graph on the same sheet of graph paper that you used for question 10. Label the line Resistor 2.

12. Repeat all the parts of question 10 using the data for R_3. Plot the graph on the same sheet of graph paper that you used for question 10 and 11. Label the line Resistor 3.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Graphical Analysis

It is worthwhile to compare the slopes for all three resistors and ask yourself what each slope says about the resistor it represents.

The slope of the potential difference versus current graph for R_1 was probably close to 1000 V/A. This means that it would take about 1000 V to make 1 A flow through R_1. Close examination of the slope for R_2 reveals that it resists the flow of current more than R_1 because it requires about 1500 V to make 1 A flow. R_3 resists the flow of current most of all because it requires about 2000 V to make 1 A flow.

resistance – the ratio of potential difference across a conductor to the current flowing through the conductor

The ratio of potential difference across a conductor to the current that flows through it is called **resistance**.

$$\text{Resistance} = \frac{\text{Potential difference}}{\text{Current}}$$

$$R = \frac{V}{I}$$

The unit of resistance is the ohm, which is symbolized by the Greek letter omega (Ω).

13. State the resistance of all three resistors in ohms.

Conclusions

14. State the relationship between the potential difference and the current for a resistor. Support your answer by referring to the graphs.

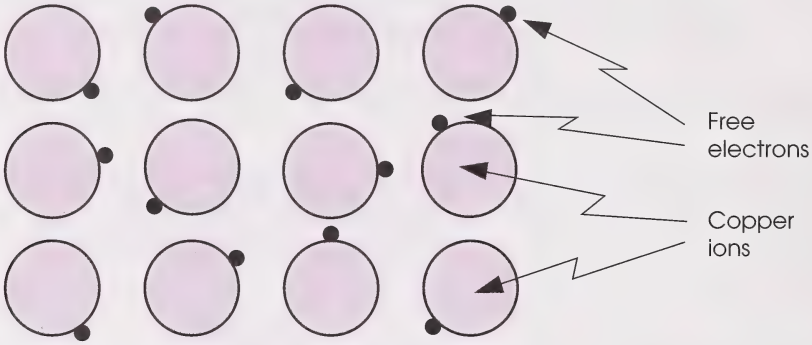
Check your answers by turning to the Appendix, Section 2: Activity 2.

The investigation allowed you to get some first-hand experience measuring potential difference and current. This investigation also introduced you to the idea of resistance.

What causes one material to have a higher resistance than another? Why did the connecting wires in your investigation stay cool while the resistor warmed up? You can answer these questions yourself with the help of some computer animation on a video program.

The video series *Electricity* contains a ten-minute program called "Resistance." Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. Note that you may have to periodically stop the tape in order to record your answers. This program may be obtained through your school or local library or it may be purchased from the Learning Resources Distributing Centre.

15. The following diagram shows the inside of a copper conductor.

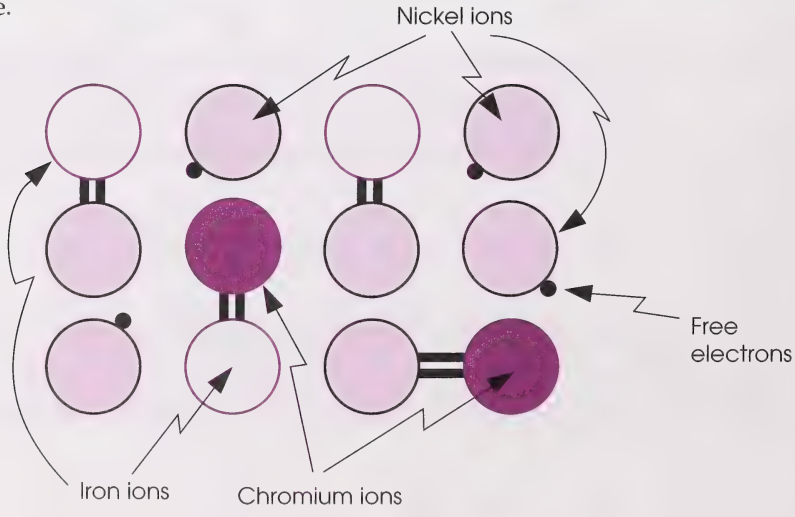


a. How does the motion of the free electrons differ from the motion of the copper ions?

b. If a strong electric field was created across the copper conductor, then how would the free electrons respond?

c. Explain why the potential difference measured across a copper conductor wire mentioned in the video is approximately zero.

16. The following diagram shows the inside of a heating element made from the alloy nichrome.



Note: The video refers to a copper conductor or a heating element as a network of positive ions with loosely held electrons. Other sources consider a copper conductor or a heating element as atoms with loosely held electrons.

a. Why are there fewer loosely held electrons in the nichrome alloy than in the copper conductor?

b. Why is a greater potential difference required to cause a current to flow through the nichrome alloy?

c. Why does the temperature increase when a potential difference is placed across a piece of nichrome alloy?

d. Why does a heating element of a stove get hot while the copper conducting wires do not?

17. Does the resistance value of a resistor change when it is connected to a different circuit? Support your answer with sample data from the video program.

18. a. Explain briefly why you should not put a large potential difference across two parts of your body.

b. Explain in terms of potential difference and resistance why a bird can sit on a high current-carrying wire?

Check your answers by turning to the Appendix, Section 2: Activity 2.

The video program made a good point about the dangers of having a high potential difference across two different parts of your body. You can gain greater insight into this idea by considering the resistance of the body under different circumstances as shown in the following chart.

APPROXIMATE RESISTANCE ACROSS A PERSON'S TWO HANDS

Circumstance	Resistance (Ω)
Both hands are dry.	1.0×10^5
Both hands are wet.	1.5×10^3

19. Suppose a student accidentally touched the leads of a power supply rated at 40 V.

    a. Calculate the current through the student's body if both hands were dry. Express your answer in milliamperes.

    b. Calculate the current through the student's body if both hands were wet. Express your answer in milliamperes.

How would you interpret your answers to the preceding question? Are current values in the milliampere range worth worrying about? As the following flow chart indicates, even small amounts of current can have serious effects on the human body.

EFFECTS OF CURRENT ON THE HUMAN BODY					
Current	**2 mA**	**10 to 20 mA**	**20 mA**	**20 to 100 mA**	**100 mA to 3A**
Effect	feel a tingle	muscular effects	can't let go of conducting wire	respiratory paralysis	fatal

20. Suppose a person accidentally touched a 120 V wire from a household circuit with one hand while the other hand touched a cold water tap. Assume that both hands are wet.

    a. If the water tap is at ground or zero potential, what is the potential difference across the hands?

    b. Calculate the current that would flow using the resistance chart presented earlier. Express your answer in milliamperes.

    c. Determine the likely effect on that peron's body using the preceding Effect of Current on the Human Body chart.

    d. Why are there special electrical codes for electrical outlets in bathrooms?

21. If a person had dry hands what would be the minimum voltage that would cause him or her to not be able to let go of two live wires? Refer to the charts presented earlier.

22. At the investigation of an industrial accident it was determined that a person suffered respiratory paralysis after touching two conductors that had 220 V across them.

    a. Calculate the range of resistance values for this person's body.

b. Speculate on the amount of moisture on the person's hands.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Visions

Clearly, even small amounts of current can be dangerous. Your textbook describes how you are protected from electric shock and other hazards associated with household wiring on pages 284 to 286. Read these pages, including all the figures, captions, and margin notes. When you've finished, answer the following questions.

23. Other than electric shock, what other hazards are created when wires carry too high a current?

24. You may have seen a defibrillator used on a patient during a television drama program.

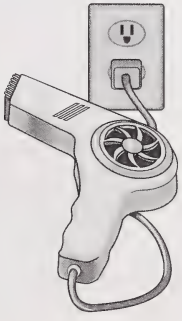
    a. Why would the healthcare professional administering this procedure say "Clear!" and wait for all others to clear away from the patient before starting.

    b. Why would the patient's body twitch, (it's usually not the violent spasm shown on television) the instant the defibrillator is initiated?

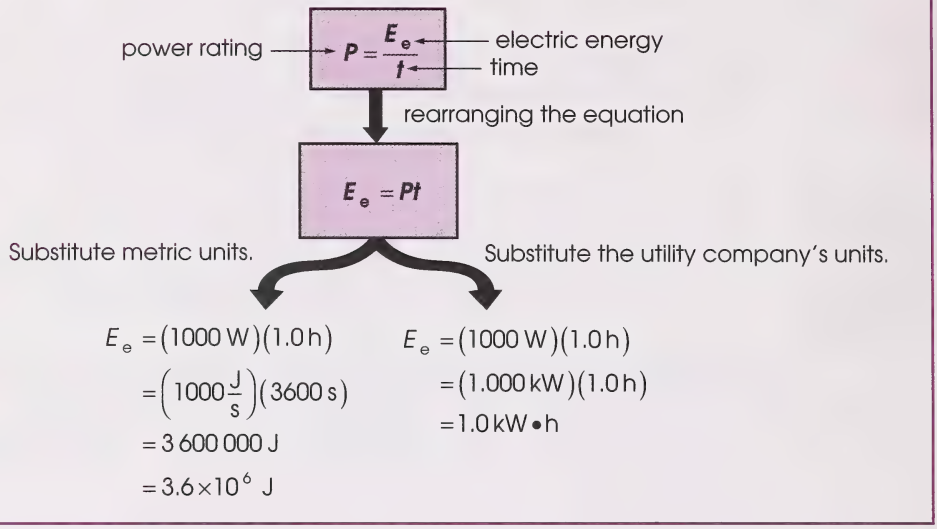
25. Perform a calculation to show that the maximum safe exposure limit for a GFCI assumes that the persons hands are more likely to be wet than dry.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Some people would argue that the only thing more painful that an electric shock is paying your electricity bill! In most municipalities the unit used to record and charge for electrical consumption is the kilowatt-hour rather than the joule. As the following question and calculation indicates, even though these units are not equal to each other, they are related.



A hairdryer rated at 1000 watts is used for 1.0 hour. How much electric energy does it use?



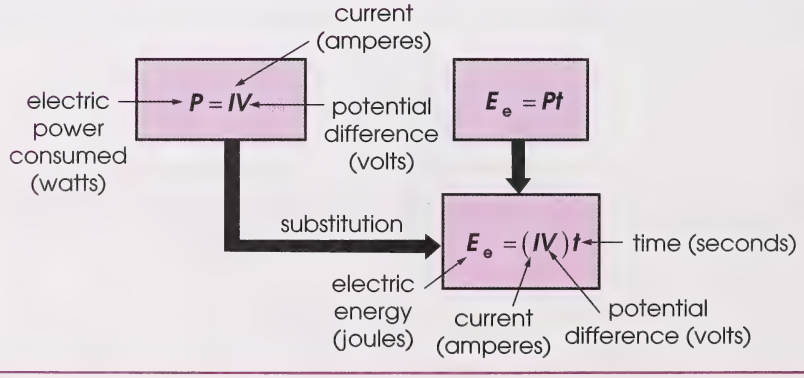
These energy values both describe the energy used. Therefore, $1.0\,kW \bullet h = 3.6 \times 10^6\,J$.

26. An 800 W microwave oven is used for 2.0 h every day for a week.

    a. Calculate the energy consumed by the oven in one week. Express your answer in kilowatt-hours.

    b. Calculate the energy consumed by the oven in one week. Express your answer in joules.

You've already learned that most simple electric circuits are described in terms of voltage, current, and resistance. Can electric power and, therefore, electric energy be calculated using these variables? As the following equations indicate, the answer is yes.



Visions

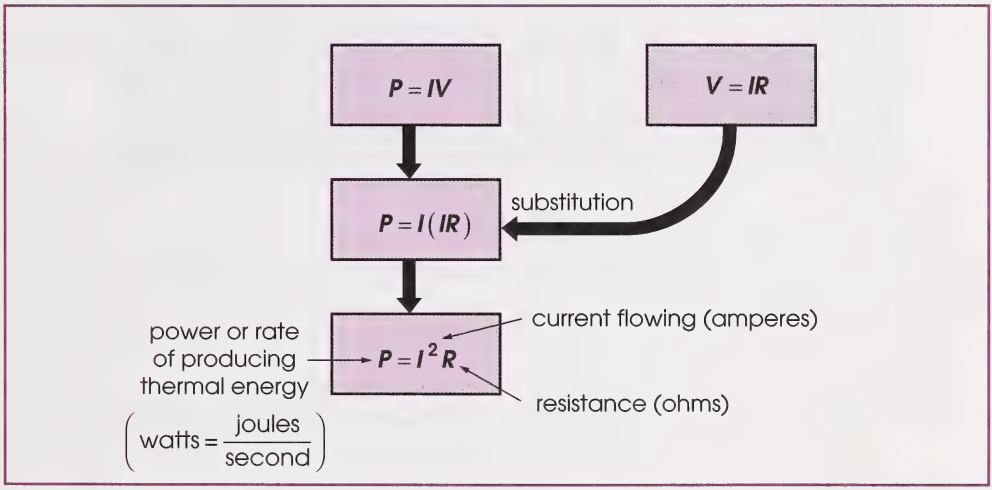
Read pages 269 and 270 of your textbook to discover the origins of the equation $P = IV$ and to see some examples of how these equations can be used.

27. Construct a flow chart to show the derivation of the equation $P = IV$.

28. Do Problems 1 to 4 on page 271 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 2.

The heating effects of wires that you read about earlier in your textbook can now be reinterpreted in terms of electric power. As the reading suggested, this heating effect is really due to the current flowing through the wires. One way to show this is to rewrite the equation for power as shown in the following flow chart.



This equation is quite useful because it helps to focus on the heating effects of high currents. Power is the rate of producing energy. You can see that current will have a significant impact on the thermal energy produced since this term is squared in the equation. The following example illustrates this point.

Example

The heating element of an electric toaster oven has a resistance of 15 Ω once it is warmed up. The temperature dial of the oven simply allows more current to flow through the element for higher temperature cooking and less current for lower temperature cooking.

Suppose the oven draws 4.0 A of current on a low temperature setting.

a. Calculate the power consumed by the oven.

b. Determine the number of joules of thermal energy released in one second.

Solution

a. $R = 15\,\Omega$

$= 15\,\frac{V}{A}$ ← $1\,\Omega = \frac{1\,V}{A}$

$I = 4.0\ A$

$P = ?$

$P = I^2R$

$= (4.0\ A)^2\left(15\,\frac{V}{A}\right)$ ← Remember to square the current.

$= (16\ A^{\cancel{2}})\left(15\,\frac{V}{\cancel{A}}\right)$

$= 2.4 \times 10^2\ V \bullet A$

$= 2.4 \times 10^2\ W$

b. Since the watt is a unit that means joules per second, if the power rating is 2.4×10^2 W, then 2.4×10^2 J are released in one second.

29. Suppose the toaster described in the preceding question was adjusted to a higher setting that caused 8.0 A to be drawn. Assume that the resistance of the heating element is still 15 Ω.

    a. Calculate the power consumed by the oven for this setting.

    b. Determine the number of joules of thermal energy released in one second.

30. Compare your answers to the preceding question to the answers shown for the example. Explain how the thermal energy produced can increase by a factor of four when the current merely doubles.

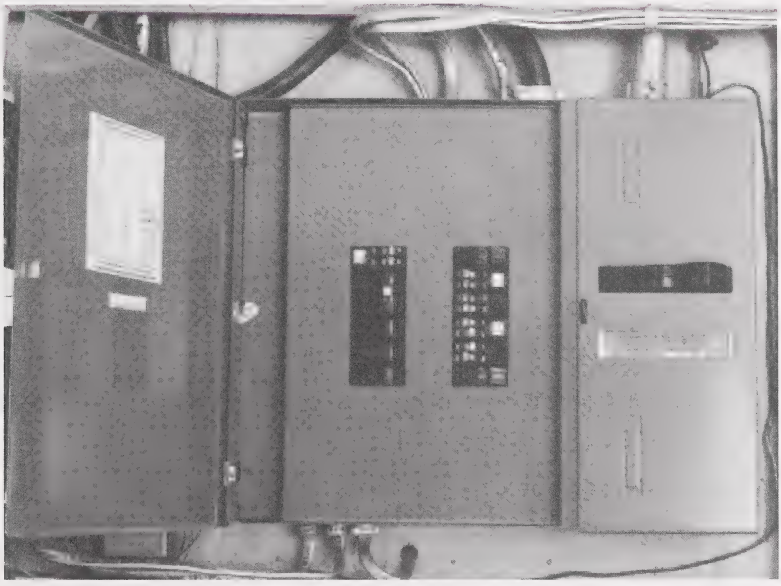
31. a. Draw a circuit diagram for a car's rear window defroster that includes the car battery, the current of 10 A, and the heating coil (1.2 Ω resistance). Use an arrow to show the direction the current flows.

    b. Calculate the number of joules of thermal energy released in one second.

    c. This circuit in the car is protected by a 20 A automotive fuse. If this fuse burned out, explain why it would not be safe to replace it with a 30 A fuse. Refer to the equation $P = I^2R$ in your answer.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Activity 3: Using Circuits



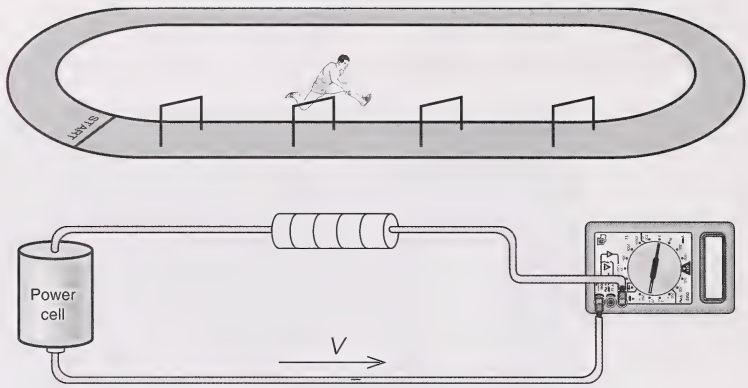
You've been planning the party for weeks and now you are madly rushing to prepare the last of the party snacks and beverages. The toaster oven is melting cheese over biscuits and the microwave oven is heating a sauce. You remember that some people like tea, so you quickly plug in the kettle …click!

All the appliances stop running. After a few seconds of disbelief, you realize what has happened. In the hurry to have everything ready for your guests, you have forgotten about the limits of the circuit for your kitchen appliances.

The loud click was the circuit breaker being tripped. You turn off all the appliances, go to the electrical panel, and open the door to find the breaker that was tripped.

Has this ever happened to you? In this particular chain of events, the microwave oven, the toaster oven, and the kettle were all connected in parallel on the same circuit. When the kettle was plugged in, the breaker was activated because the current through it exceeded safe limits. The kettle caused more current to flow through the circuit than it was designed to handle due to the characteristics of parallel circuits.

In this activity you will investigate the properties of series circuits, parallel circuits, and combination circuits. The results of the investigations will be used to derive equations and principles that can be applied to a number of everyday situations.



In the first drawing the runner runs around the track and jumps hurdles. The runner starts at a spot on the track and eventually returns to the same spot. You would say that the athlete is running in circles. In the second drawing the electron is moving around a circuit.

In a series circuit there is only one path for the electrons to follow. They start at the battery and go along a single path until they return to the battery, where their electric potential energy is increased so that they can repeat the process.

Science Skills
- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: The Series Circuit

Purpose

The purpose of this investigation is to determine the properties of a series circuit.

Materials

You will need the following materials for this investigation:

- a DC power supply capable of producing at least six different output voltages (0 V to 20 V)
- a multimeter capable of measuring potential difference (0 V to 20 V), current (0 mA to 20 mA), and resistance (200 Ω to 5000 Ω)
- three resistors rated at 0.5 W power handling, 5% tolerance:

  R_1 = 510 Ω (green, brown, brown, gold)
  R_2 = 1000 Ω (brown, black, red, gold)
  R_3 = 1500 Ω (brown, green, red, gold)

- six test leads with alligator clips at both ends
- three pieces of masking tape, each measuring about 40 mm by 5 mm

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch objects, such as metal pipes, electric outlets, and light fixtures, that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Background Information

Resistors are usually identified by means of a striped colour code. Although you will always be given the colour code of individual resistors, you may be interested to know how the code works. The first two stripes represent the first two digits in the value of the resistance. The third stripe represents the multiplier (or power of ten) that the first two digits must be multiplied by. The fourth stripe represents the manufactured tolerance. The following chart summarizes the code.

You may find it interesting to check the colour code of the resistors described in the Materials section of this investigation.

Colour	Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White	Gold	Silver	No colour
Number	0	1	2	3	4	5	6	7	8	9			
Multiplier	1	10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	10^{-1}	10^{-2}	
Tolerance											5%	10%	20%

Procedure and Observations

Read the entire Procedure and Observations section before you begin. You will be asked to write your observations into a data chart as you do the procedure. A completed data chart will be included in the Appendix for your reference.

1. • Copy the following chart into your notebook. Complete the chart by filling in the missing values with your measurements as you follow the procedure.

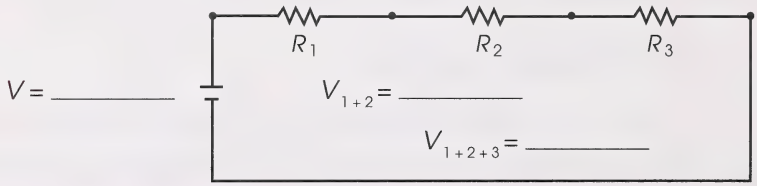
$R_1 =$ _____ $R_2 =$ _____ $R_3 =$ _____

$V_1 =$ _____ $V_2 =$ _____ $V_3 =$ _____

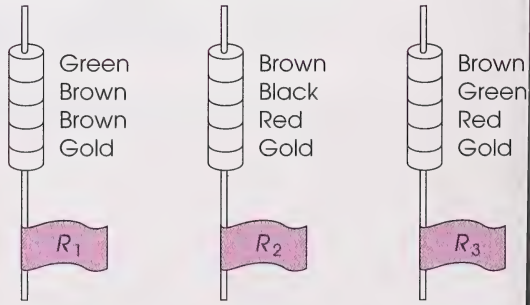
$I_1 =$ _____ $I_2 =$ _____ $I_3 =$ _____

$R_{1+2} =$ _____ $R_{1+2+3} =$ _____

Note: R_{1+2} and R_{1+2+3} are measured values.



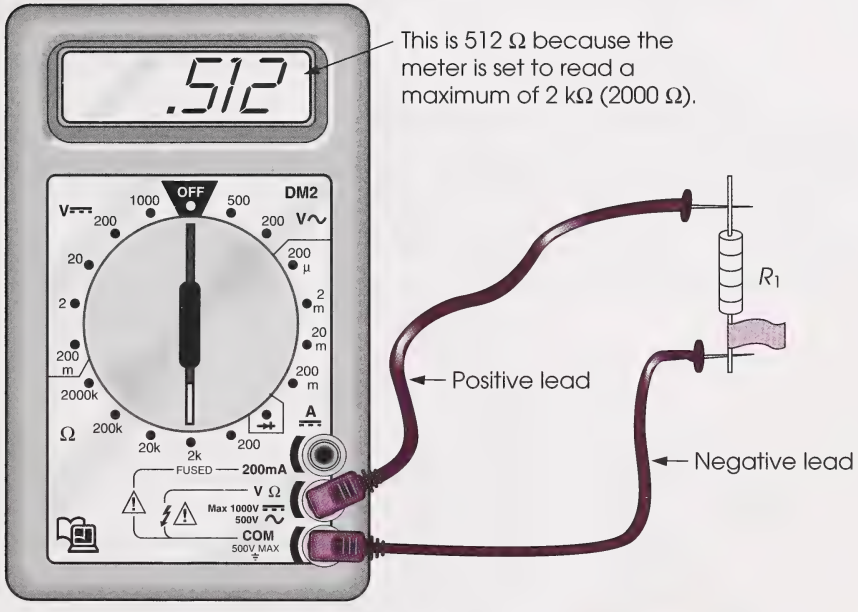
• Wrap the tape around the wire lead of each resistor, as shown in the following sketch.



- Label the resistors R_1, R_2, and R_3. Be careful to match the number to the correct sequence of stripes on each resistor.

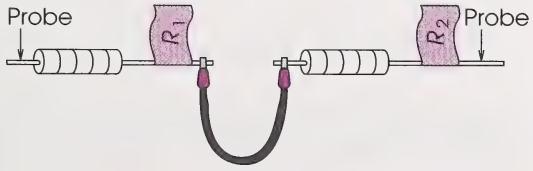
Measuring Resistance Values

- Set the dial on the multimeter to measure resistance in ohms and determine the resistance of each resistor by touching the leads across each resistor. The following diagram shows the proper technique for a typical multimeter.



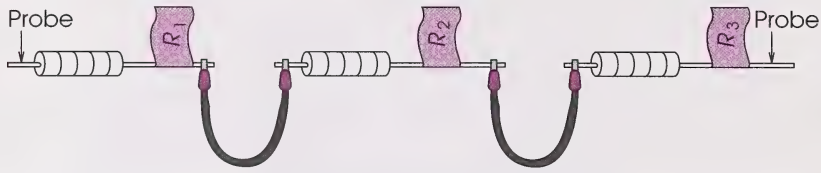
- Record the resistance of the three resistors on the data chart.

- Use a connecting wire to attach R_1 to R_2. Measure the resistance of R_1 and R_2 in series. Note that one probe of the multimeter is to be connected to the open end of R_1, while the other probe is connected to the open end of R_2.



- Record the resistance of R_1 and R_2 in series on the data chart.

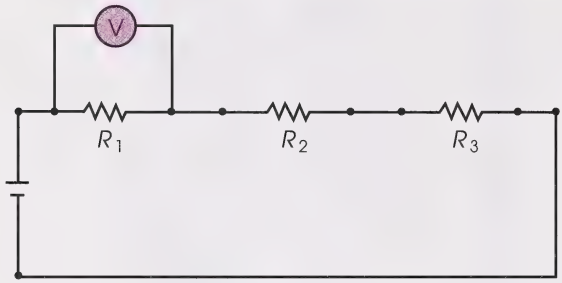
- Use a connecting wire to attach R_3 in series with R_1 and R_2. Measure the resistance of these three resistors in series. You may have to change to the 20-kΩ scale to get a resistance value for this setup.



- Record the value of R_1, R_2, and R_3 in series on the data chart.

Measuring Potential Difference

- Without turning on the power supply, construct the following circuit.



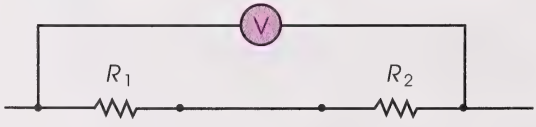
- Adjust the power supply to a constant output of between 12 V and 20 V depending on the settings on your power supply. Once you have this set, do not change it again throughout the experiment.

- Inspect the circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected parallel with the resistor.

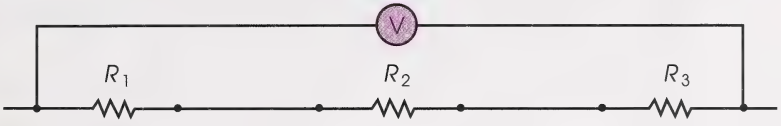
- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous activity.

- Turn on the power supply. Record the potential difference of the voltmeter across each resistor. Record your values on the data chart.

- Record the potential difference of the voltmeter across R_1 and R_2. The following diagram of part of the circuit shows how. Record this value on the data chart.



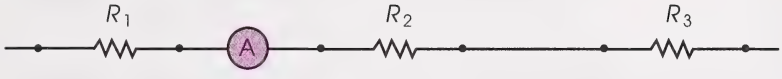
- Record the potential difference of the voltmeter across R_1, R_2, and R_3. The following diagram of part of the circuit shows how to do this. Record this value on the data chart.



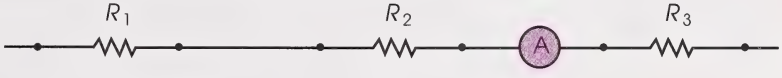
- Disconnect the power supply from the circuit as soon as your measurements are complete.

Measuring Current

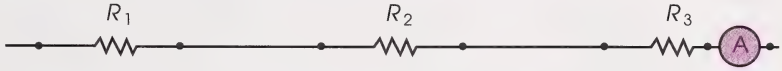
- Adjust the leads and the dial on the multimeter to measure current. To measure current, you have to have the multimeter in series with the resistors. To measure the current through R_1, have the meter in series between R_1 and R_2. To put the meter in series, disconnect the alligator clip that is between R_1 and R_2 from R_1 and touch the meter leads to R_1 and the alligator clip attached to R_2. The following diagram of part of the circuit shows how to do this. Record the current measured by the ammeter on the data chart.



- Reconnect the alligator clip to R_1 and disconnect the alligator clip that is between R_2 and R_3 from R_2. Add the multimeter at this point. Record the current measured by the ammeter through R_2 as shown in the following diagrams of part of the circuit. Record these values on the data chart.



- Add the multimeter after R_3, as in the diagram which follows, using a procedure similar to the preceding one. Record the current measured by the ammeter through R_3.



- Save the resistors, complete with the tape labels, so that they can be used in the next investigation.

Analysis and Interpretation

2. The potential difference across all three resistors, V_{1+2+3}, relates to the voltage output of the power supply. What do these measurements reveal the output of the power supply to be?

3. How do the individual voltage drops across each resistor relate to the total voltage output of the power supply?

4. Explain your answer to the preceding question in terms of energy.

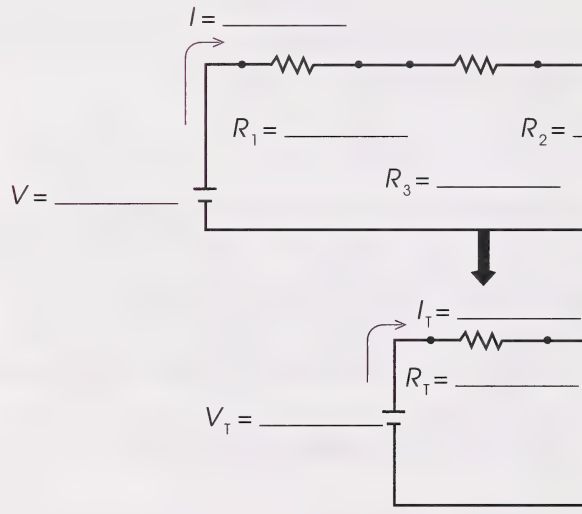
5. How do the individual values for the current through each resistor compare to each other? How do the individual current values through each resistor compare to the current output by the power supply?

6. Explain your answer to the preceding question.

7. How do the individual values for resistance compare to the total resistance across all three resistors?

8. Copy the following flow chart into your notebook. Complete the flow chart by labelling the values of each of the quantities indicated. Use the data chart that you completed to find the values.

Original Circuit



If all the resistors were replaced with an **equivalent resistance**, R_T, and the current did not change, the circuit would look like this.

I_T is the total current through the whole circuit and V_T is the total potential difference across the whole circuit.

equivalent resistance – the value of a single resistor that could replace a group of resistors in a circuit and not change the current

9. Calculate a theoretical value of R_T using V_T and I_T. How does the actual value of R_T compare?

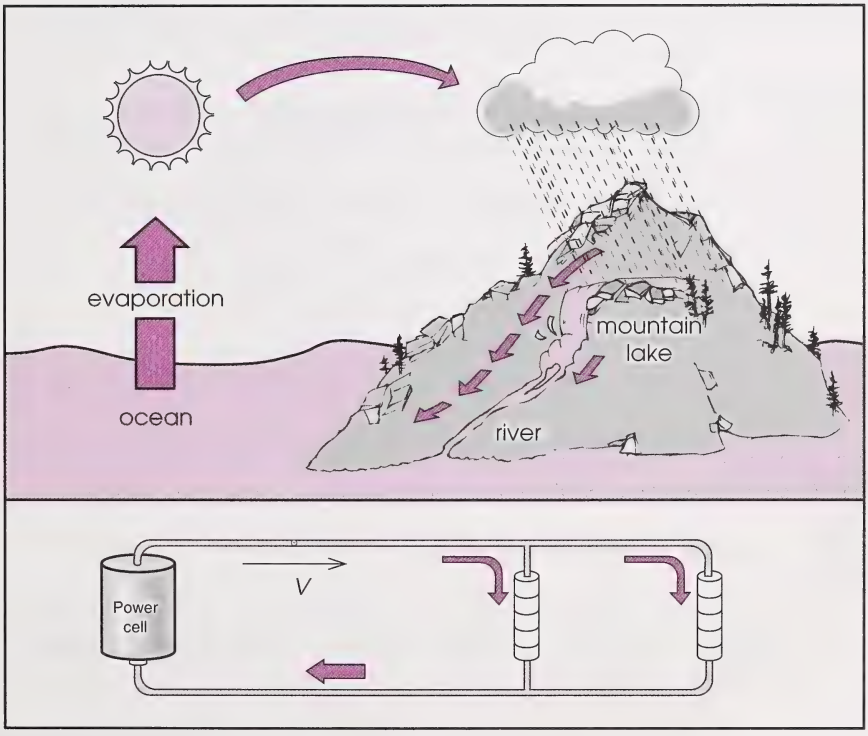
Check your answers by turning to the Appendix, Section 2: Activity 3.

Conclusions

Looking at your answers to the Analysis questions, you should be able to make the following generalizations about the properties of a series circuit.

$$R_T = R_1 + R_2 + R_3 + \ldots$$
$$V_T = V_1 + V_2 + V_3 + \ldots$$
$$I_T = I_1 = I_2 = I_3 = \ldots$$
$$V_T = I_T R_T$$

In the next investigation you will investigate the properties of parallel circuits. However, it might be a good idea to review the basic idea behind a parallel circuit by examining the following diagram.



In the first illustration water flows down from the mountains to the sea or ocean. The river breaks into different paths, but later on it joins up again. In the second illustration the electrons also branch and then rejoin to create a single path.

In this investigation you will see circuits that follow the same pattern illustrated in these diagrams. Electrons flow in the wire, but at times they arrive at a junction and split up for a while and then rejoin at another place. Keep this comparison in mind as you complete the following investigation.

Investigation: The Parallel Circuit

Purpose

It is the purpose of this investigation to determine the properties of a parallel circuit.

Materials

You will need the following materials for this investigation:

- a DC power supply capable of producing at least six different output voltages (0 V to 20 V)
- a multimeter capable of measuring potential difference (0 V to 20 V), current (0 mA to 50 mA), and resistance (200 Ω to 5000 Ω)
- three resistors rated at 0.5 W power handling, 5% tolerance:

  R_1 = 510 Ω (green, brown, brown, gold)
  R_2 = 1000 Ω (brown, black, red, gold)
  R_3 = 1500 Ω (brown, green, red, gold)
  Note: These are the same three resistors used in the previous activity.

- six test leads with alligator clips at both ends

- three pieces of masking tape, each measuring about 40 mm by 5 mm

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch objects, such as metal pipes, electric outlets, and light fixtures, that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.

- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.

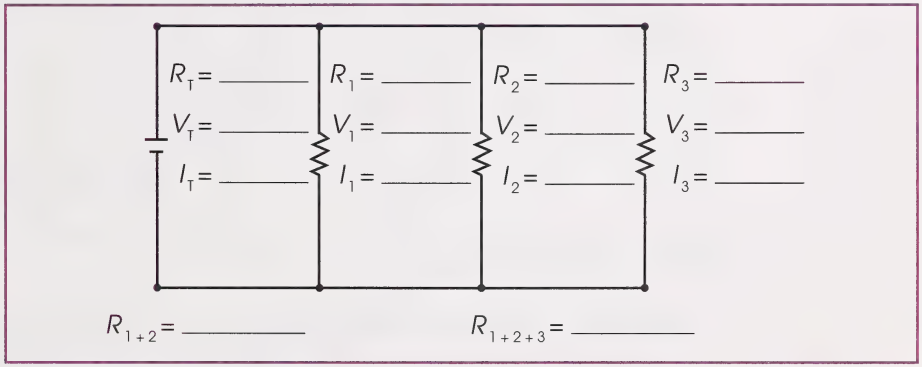
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure and Observations

Read the entire Procedure and Observations section before you begin. You will be asked to record your observations in a data chart as you do the procedure. A completed data chart will be included in the Appendix for your reference.

10. • Copy the following chart into your notebook. Complete the chart by filling in your observations as you do the procedure.



- If you saved the three resistors from the previous investigation, you may use them again for this investigation. If you did not save the resistors from the last investigation, you will have to label some with masking tape as you did for the other investigation. Refer to the instructions in the previous investigation.

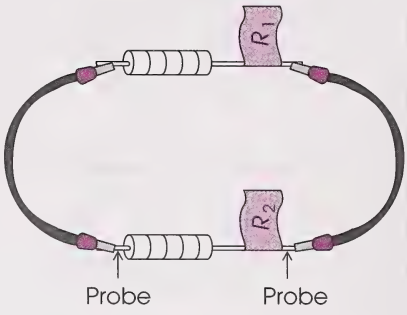
Measuring Resistance

- Set the dial and the input leads of the multimeter to measure resistance.

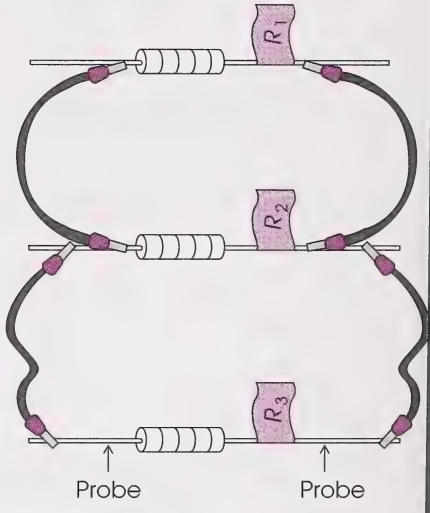
- If you are using the same resistors as in the previous investigation, you can use the resistance values that you obtained in the previous investigation. If you are using different resistors, you will need to measure the resistance of each one. Refer to the previous investigation for specific instructions.

- Record the values of the individual resistors on the data chart.

- Connect R_1 and R_2 in parallel. Measure the resistance of the combination, as shown in the following diagram. Record this value in the data chart.

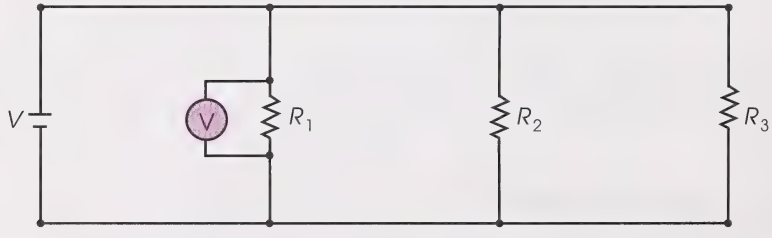


- Connect R_1, R_2 and R_3 in parallel. Measure the resistance of this combination, as shown in the following diagram. Record this value in the data chart.



Measuring Potential Difference

- Without turning on the power supply, construct the following circuit.



- Adjust the power supply to provide a constant output of between 5 V and 10 V. Once you have this output set, do not change it again throughout the experiment.

- Inspect the circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected in parallel with the resistor.

- If you are in a school lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagrams that were provided in the previous activity.

- Turn on the power supply. Measure the potential difference across R_1. Record this value on the data chart.

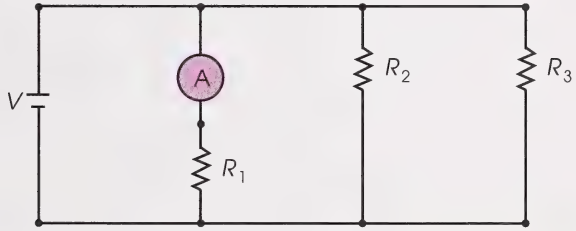
- Repeat the preceding step by touching the probes to the ends of resistors R_2 and R_3. Record these values of potential difference on the data chart.

- Measure the potential difference, V_T, provided by the power supply while it is connected to the resistors. Record this value on the data chart.

Measuring Current

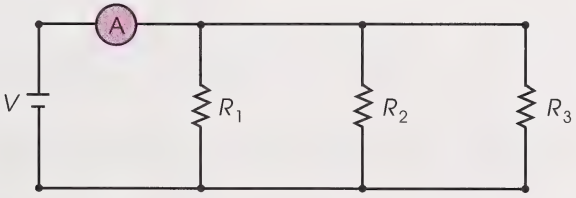
- Adjust the leads and the dial on the multimeter to measure current. To measure current, you have to have the multimeter in series with the resistors.

- Connect the multimeter in series to the branch of the circuit containing R_1, as shown in the following diagram. Record the current measured by the ammeter through R_1 on the data chart.



- Repeat the preceding two steps for each of the other resistors. Record the current values on the data chart.

- Connect the multimeter in series with the power supply, as shown in the following diagram. Record the value of the total current, I_T, measured by the ammeter on the data chart.



Analysis and Interpretation

11. How do the individual voltage drops across each resistor relate to the total voltage output of the power supply?

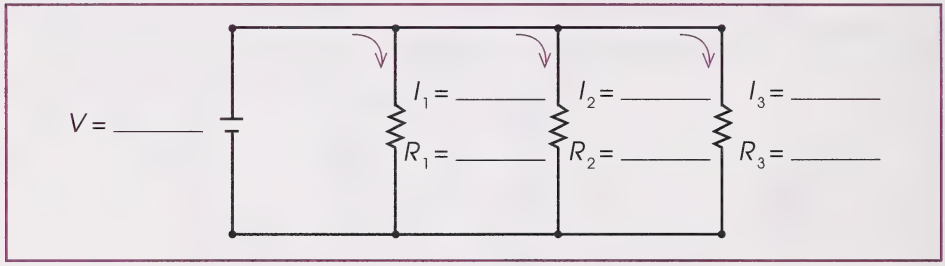
12. Explain your answer to the preceding question in terms of energy.

13. How do the individual values for the current through each resistor compare to the total current provided by the power supply?

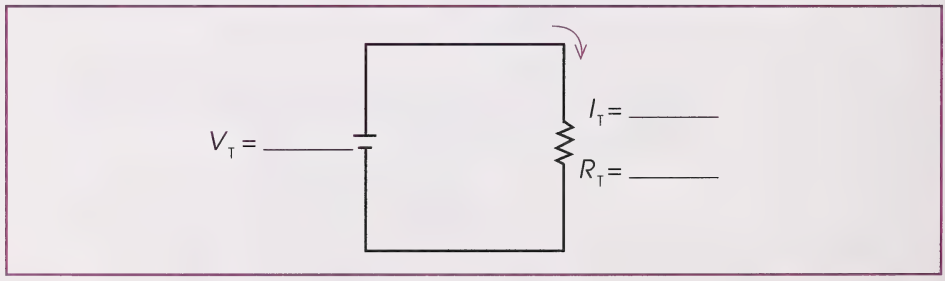
14. Explain your answer to the preceding question.

15. How do the individual values for resistance compare to the total resistance of all three resistors connected in parallel?

16. Copy the following diagram into your notebook. Complete the diagram by labelling the values of each of the quantities indicated. Use the data chart that you completed to find the values.



If all the resistors were replaced with an equivalent single resistor, R_T, such that the total current did not change, the circuit would look like this.



17. Calculate a theoretical value for R_T using V_T and I_T. How does the actual value of R_T compare?

Although it may seem strange at first, it does make sense that the total resistance of the three resistors in parallel is less than the individual values. Each resistor that is added in parallel provides another path for current, allowing more current to flow and lowering the overall resistance.

The following derivation shows that an equation can be developed for the equivalent resistance of a parallel circuit.

$$I_T = I_1 + I_2 + I_3$$

Apply Ohm's law to each current value.

$$\frac{V_T}{R_T} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

Since $V_T = V_1 = V_2 = V_3$, these values can be replaced with V.

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Divide all terms by V.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

18. Using the measured values of R_1, R_2, and R_3, calculate the total resistance, R_T, using the preceding equation. How does this value for R_T compare to the measured value of R_T?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Conclusions

Look at your answers to the Analysis questions; you should be able to make the following generalizations about the properties of parallel circuits.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

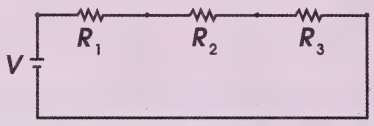
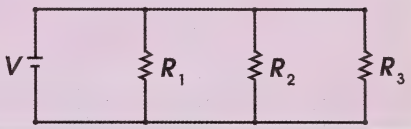
$$V_T = V_1 = V_2 = V_3$$

$$I_T = I_1 + I_2 + I_3 + \ldots$$

$$V_T = I_T R_T$$

Now that you've made measurements that show the differences between series and parallel circuits, it would be a good idea to summarize and then apply what you've learned.

19. Copy the following chart into your notebook, being careful to leave enough space under each heading to record your answers. Complete the chart by concisely recording your answers to the questions in point form.

Questions for Comparison	The Series Circuit 	The Parallel Circuit 
If another resistor is added, what would be the effect on the equivalent resistance of the whole circuit?		
If another resistor is added, what would be the effect on the total current drawn by the circuit?		
If R_3 was simply disconnected and removed from the circuit, what changes would occur in this circuit?		

Check your answers by turning to the Appendix, Section 2: Activity 3.

The answers to the preceding question can provide some interesting insights into the applications of series and parallel circuits. Keep this in mind as you answer the next questions.

20. Why is it so inconvenient for the bulbs in sets of Christmas tree lights to be connected in series?

21. If you look at the electrical panel for most houses or apartments you'll find that bedroom lights are often all put on the same circuit. Is this a series or parallel circuit? Explain concisely.

22. Reread the first four paragraphs that introduced this activity. Explain what happened when the kettle was plugged in.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

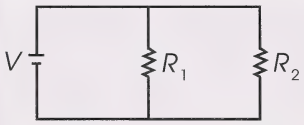
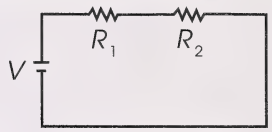
In this section you have learned a number of new terms, equations, and units. The following question will help you to consolidate this information by summarizing it in chart form.

1. Copy the following chart into your notebook, being careful to leave enough space under each heading to record your answers. Complete the chart by filling in the blank spaces.

Term	Definition	Symbol	Unit(s)	Related Equation(s)
		V		$V = \frac{E_e}{q}$
current				
electric field across two parallel plates				$\lvert\vec{E}\rvert = \frac{V}{d}$
		R		
electric power				
		E_e		

This section has also introduced you to the properties of series and parallel circuits. The following question will help you to summarize these ideas.

2. Copy the following chart into your notebook, being careful to leave enough space under each heading to record your answers. Complete the chart by recording the missing information.

COMPARING SERIES AND PARALLEL CIRCUITS		
Type of Circuit		
Schematic Diagram		
General properties of this type of circuit		

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Choose one of the following activities.

1. It's easy to take for granted the work and contributions of the scientists who are pioneers in a field. It's interesting to know that sometimes their greatest challenge is dealing with the attitudes and prejudice of other scientists. This was very much the case for Georg Simon Ohm. Visit a local library and research the life and accomplishments of Ohm. Write a short report that outlines the unkind treatment Ohm received from the scientific community.

Visions

2. Turn to Figure 8.2 on page 260 of your textbook. Use the idea that potential energy equals the work done to change position, as well as other definitions from this section, to derive the equation $V = |\vec{E}|d$.

3. Imagine that you have six 1.0 kΩ light bulbs and want to light up your deck. How should you connect them (series or parallel) so that it won't be expensive to leave them on at night? Assume that you want to leave them on for 8.0 h and the cost is 7.0¢/kW • h.

   a. Draw the schematic diagram for both scenarios.

   b. Calculate the cost for both scenarios. Assume that you run the lights from a 120 V source.

c. Which is the least expensive setup?

d. Which setup would give you the most light?

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

This section began by asking you to speculate about the function of batteries in simple electric circuits. Now that you've finished the activities in this section you should know that a battery is a device that converts chemical energy to electric energy. The ability of a battery to give energy to charges is described in terms of potential difference. Current and resistance are other quantities that can describe a simple electric circuit. The investigations in this section gave you an opportunity to measure these quantities and to see how they differ in both series and parallel circuits. The next time you encounter an application of a simple electric circuit, you should be able to understand the main concepts and the meaning of units like volts, amperes, and ohms.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

This module has provided numerous examples of how something as abstract as a field can translate into a significant practical application. Gravitational fields, for example, can provide important clues for growth in the root cells of plants, while magnetic fields are used by many species for navigation/migration purposes.

Circuits were explored in detail as a spinoff of the electric field. You've seen that concepts like energy can be combined with the ideas from this module to develop new measurements that are exceptionally useful in describing electric circuits. Potential difference, current, and resistance are fundamental ways to describe the characteristics of most circuits.

In the next module you will continue to apply the field concepts as you investigate the interaction of electric fields with magnetic fields.

Appendix

Glossary

Suggested Answers

Glossary

ampere: the unit of electric current $\left(1\,\text{A} = \frac{1\,\text{C}}{\text{s}}\right)$

circuit: a closed loop that charges can flow around

coulomb (C): the unit of charge in the SI system

Coulomb's law: the law that describes the electrostatic force between two charged objects

current: the ratio of the amount of charges that pass a point per unit of time $\left(I = \frac{q}{t}\right)$

domains: groups of neighbouring atoms that produce magnetic fields that align in the same direction

discharging: the process of losing charge and being neutralized

electric conductor: a material through which charge easily moves

electric field: the space surrounding a charge in which other charges will experience an electrostatic force

electric field strength: a vector that indicates the force per unit of a positive test charge

electric field line: an imaginary line that shows the electric field around a charged object

electric insulator: a material through which charge does not easily move

electric potential difference: the ratio of change in potential energy per unit of charge $\left(V = \frac{\Delta E_{\text{p}}}{q}\right)$

electric power: the ratio of the electric energy used per unit of time

equivalent resistance: the value of a single resistor that could replace a group of resistors in a circuit and not change the current

geosynchronous satellite: a satellite that remains above the same point on Earth's surface

grounding: the act of touching a charged object to the earth to eliminate excess charge

gravitational constant: the physical value needed in Newton's law of gravitation to determine the actual force between two bodies

gravitational field: the space surrounding a mass in which other masses within the region will experience a gravitational force

gravitational field strength: represented by a vector that indicates the force per unit of mass

gravitational force: a force of attraction between two bodies due to their masses

ion: an atom that has gained or lost electrons, leaving it with a net negative or positive charge

kilowatt hour: a unit for electric energy used frequently by utility companies

$1\,\text{kW} \bullet \text{h} = 3.6 \times 10^{6}\ \text{J}$

law of conservation of charge: a law stating the total amount of charge in a closed system remains constant

magnetic field: the region surrounding a bar magnet in which a magnetic force exists

magnetic field lines: lines along which a magnetic force exists within a magnetic field

magnetic flux: density of magnetic field lines in a given space or area

magnetic force: a force that exists within a magnetic field

multimeter: a device that can measure a wide range of voltages, currents, and resistances in an electric circuit

negatively charged: an object that has an excess of electrons

ohm: the unit of resistance $\left(1\Omega = \frac{1\text{V}}{\text{A}}\right)$

Ohm's law: The ratio of the potential difference across a conductor to the current that flows across the conductor is constant $\left(R = \frac{V}{I}\right)$.

parallel connection: more than one path is available for electron flow through devices connected in parallel

point charge: an idealized charge that is so small that it takes up no space

positively charged: an object that has a deficit of electrons

potential difference: an abbreviated term meaning the same thing as electric potential difference

resistance: the ratio of potential difference across a conductor to the current flowing through the conductor

resistor: a device that resists the flow of charge and has a constant resistance

series connection: only one path is available for electron flow through devices connected in series

volt: the unit of electric potential difference
$1\text{V} = \text{J/C}$

voltage: a common term meaning the same thing as electric potential difference

Suggested Answers

Section 1: Activity 1

1. $m_E = 5.97\times10^{24}\ \text{kg}$

$m_s = 1.99\times10^{30}\ \text{kg}$

$G = 6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}$

$r = 1.50\times10^{11}\ \text{m}$

$F_g = ?$

$$F_g = \frac{Gm_s m_E}{r^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}\right)\left(1.99\times10^{30}\ \text{kg}\right)\left(5.97\times10^{24}\ \text{kg}\right)}{\left(1.50\times10^{11}\ \text{m}\right)^2}$$

$$= 3.5218\times10^{22}\ \text{N}$$

$$= 3.52\times10^{22}\ \text{N (3 significant digits)}$$

The force of gravitational attraction between the sun and Earth is 3.52×10^{22} N.

2. Cavendish used lead spheres because they are relatively massive (lead has a large mass per unit volume) and they result in a greater gravitational force of attraction.

3. Cavendish kept the lead spheres enclosed so that the rotational motion of the spheres on the wire would not be influenced by air currents.

4. The small value for G means that the force of gravity calculated for two objects will be quite small. In general, only very massive objects, such as stars or planets or large moons, create a significant gravitational force.

5. $m_1 = 65\ \text{kg}$
$m_2 = 65\ \text{kg}$
$r = 1.0\ \text{m}$
$F_g = ?$

$$F_g = \frac{Gm_1m_2}{r^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}\right)(65\ \text{kg})(65\ \text{kg})}{(1.0\ \text{m})^2}$$

$$= 2.818\times10^{-7}\ \text{N}$$

$$= 2.8\times10^{-7}\ \text{N}\ \text{(2 significant digits)}$$

This force is very small. Neither person would notice it.

Section 1: Activity 2

1. $$F_g = \frac{Gm_Em_m}{r^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\bullet\text{m}^2}{\text{kg}^2}\right)(5.98\times10^{24}\ \text{kg})(7.34\times10^{22}\ \text{kg})}{(3.80\times10^{8}\ \text{m})^2}$$

$$= 2.03\times10^{20}\ \text{N}\ \text{(3 significant digits)}$$

2. A scalar field assigns a number to each point in space, but it includes no indication of direction. Temperature is an example of a scalar field because it can provide a measurement (in degrees Celsius) for each point in space with no direction included.

   A vector field assigns both a number and a direction to each point in space. Wind velocity is an example of a vector field because each point could be measured in terms of the magnitude of the velocity (as measured in m/s or km/h) and the direction of the velocity (as indicated by north, south, east, or west).

3. Another name for gravitational field strength is the acceleration due to gravity.

4. No, gravitational field is not a force. The gravitational field is the invisible connection that allows one object to exert an attractive force on some other object, even though they are not touching. Gravitational field strength is measured in newtons per kilogram. The gravitational force, on the other hand, is the actual pull on an object and it is measured in newtons.

5. The direction of the gravitational field is the same as the direction of the gravitational force on a test mass. Since test masses would be attracted to the centre of Earth, this is the way that the gravitational field vectors should point.

6. If you go twice as far from Earth, then the gravitational field strength would be only one-quarter of the original value.

7. $F_g = 3.6\ \text{N}$

$m = 370\ \text{g or } 0.370\ \text{kg}$

$g = ?$

$$F_g = mg$$

$$g = \frac{F_g}{m}$$

$$= \frac{3.6\ \text{N}}{0.370\ \text{kg}}$$

$$= 9.7\ \frac{\text{N}}{\text{kg}} \quad \text{(2 significant digits)}$$

8. Mass measures the quantity of matter in an object.

9. a. $$g = \frac{Gm_E}{r_E^{\,2}}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N} \bullet \text{m}^2}{\text{kg}^2}\right)\left(5.98 \times 10^{24}\ \text{kg}\right)}{\left(6.37 \times 10^{6}\ \text{m}\right)^2}$$

$$= 9.83\ \frac{\text{N}}{\text{kg}}$$

b. $$g = \frac{Gm_E}{r_s^{\,2}}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N} \bullet \text{m}^2}{\text{kg}^2}\right)\left(5.98 \times 10^{24}\ \text{kg}\right)}{\left(4.23 \times 10^{7}\ \text{m}\right)^2}$$

$$= 0.223\ \frac{\text{N}}{\text{kg}}$$

c. $$g = \frac{Gm_E}{r_m^{\,2}}$$

$$= \frac{\left(6.67 \times 10^{-11}\ \frac{\text{N} \bullet \text{m}^2}{\text{kg}^2}\right)\left(5.98 \times 10^{24}\ \text{kg}\right)}{\left(3.80 \times 10^{8}\ \text{m}\right)^2}$$

$$= 0.002\,76\ \frac{\text{N}}{\text{kg}}$$

10. **Textbook question 1:**

$m_m = 7.349 \times 10^{22}$ kg

$r = 3.845 \times 10^8$ m

$g = ?$

$$g = \frac{Gm_m}{r^2}$$ (Note: m_m means mass of moon not mass times mass.)

$$= \frac{\left(6.67 \times 10^{-11} \frac{\text{N} \bullet \text{m}^2}{\text{kg}^2}\right)\left(7.349 \times 10^{22}\ \text{kg}\right)}{\left(3.845 \times 10^8\ \text{m}\right)^2}$$

$$= 3.32 \times 10^{-5} \frac{\text{N}}{\text{kg}}$$ (3 significant digits)

Textbook question 2:

$$\frac{5.931 \times 10^{-3} \frac{\text{N}}{\text{kg}}}{3.32 \times 10^{-5} \frac{\text{N}}{\text{kg}}} = 178.6$$

$= 179$ (3 significant digits)

The gravitational field strength of the sun is about 179 times greater than the gravitational field strength of the moon.

11. The gravitational field of Earth is thought to have pulled a large meteor into Earth's atmosphere. The impact of this collision is suspected to have caused so much dust to be in the atmosphere that winter-like conditions existed for hundreds of years. This is thought to have led to the extinction of the dinosaurs.

12. The Banff-Jasper gravity anomally is an area around Banff and Jasper of unusually low gravitational field strength.

13. The gravitational field keeps the bones of your body continually under load. This prevents the bones from losing mass.

14. The amyloplasts in root cells inhibit growth in the lower cell wall causing the root cells to grow down in the direction of the gravitational field.

Section 1: Activity 3

1. Atoms are electrically neutral because they contain just as many negatively charged particles (electrons) as positively charged particles (protons). The net charge is zero.

2. Electrons are transferred from the acetate strip to the cotton cloth.

3. a. If the two balloons are both negatively charged, there will be a repelling force between the balloons.

   b. If the two balloons both have a positive charge, there will be a repelling force between the balloons.

   c. If one balloon has a negative charge and the other has a positive charge, there will be an attractive force between the balloons.

4. a. Rubbing an object removes negative electrons from one object, making one object negative and leaving the other positive. **Note:** You have **not** created charges, you have only rearranged them. The law of conservation of charge is maintained because the total charge between the two objects remains constant.

   b. Electrons are transferred.

c.

Object	Indicate whether the object has lost or gained electrons.	Indicate the type of ion formed in the object.	Indicate the net charge on the object.
Rubber	gained electrons	negative ion	negative
Wool/Fur	lost electrons	positive ion	positive

d. The nuclei make up the matter or mass of a substance and are bound to the lattice structure of a solid object. No mass (except the electrons) transfers between solids.

5. a. The electric attraction between the negative electron and the positive nucleus holds the electrons within the atom.

   b. No, the electrons in the outermost orbit are loosely bound to the atom. They are called valence electrons.

6. a. A conductor is a substance that allows a charge to move easily within it.

   b. These electrons are called free electrons and are not tightly bound to any nucleus of any atom, and are free to move about.

   c. Copper, aluminum, and graphite are all good conductors.

7. a. An insulator is a substance that does not allow charges to move freely within it.

   b. All charges within an atom in an insulator are either bound to a particular nucleus or they are involved in a bond between neighbouring atoms. No electrons are free to move about.

   c. Glass, dry wood, and cloth are all good insulators.

8. The electrostatic force is affected by the two charges involved and the distance between their centres.

9. As the magnitudes of the two charges increase, the electrostatic force increases.

10. As the distance between the two charges increases, the electrostatic force decreases.

11. There is an electrostatic force acting between Balls A and B.

12. The force will be repulsive because the charges are both negative.

13. Ball A will rotate counterclockwise since it is repelled from Ball B.

14. Since Ball A is a conductor, as is Ball B, charge will flow from one metal ball to the other until the charge on each is the same.

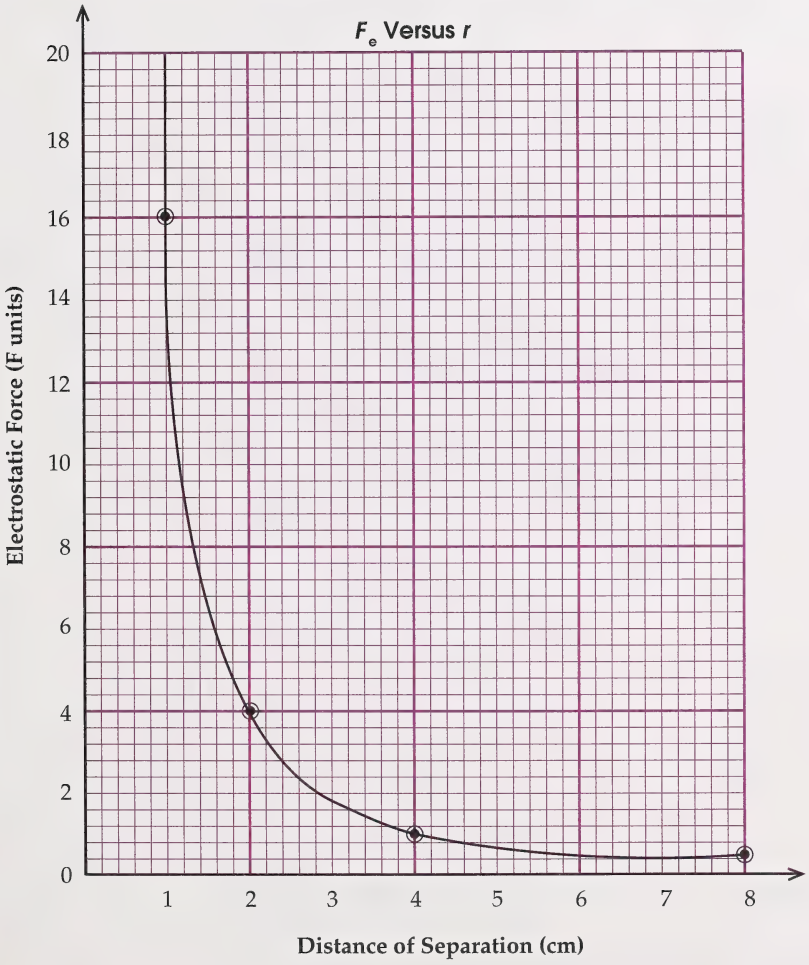
15. a. The total charge must be equivalent to q_B, as stated by the law of conservation of charge.

    b. Since they share charge on contact, the charge on Ball A will be $\frac{1}{2}q_B$ and the charge on the Ball B will be $\frac{1}{2}q_B$.

16. Your chart should look similar to the chart shown.

Distance Between Two Charged Objects (r) in cm	Electrostatic Force (F) in F units
1.0	16.0
2.0	4.0
4.0	1.0
8.0	0.5

17.

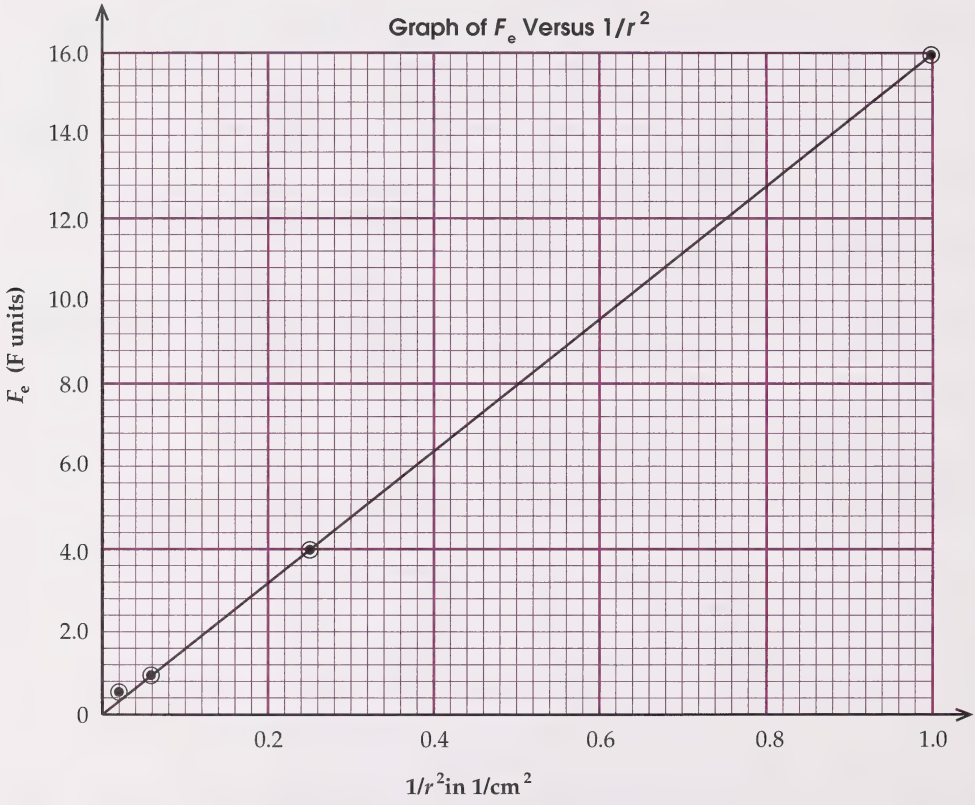


18. The graph is a smooth curve. The shape of the curve suggests that as the distance of separation gets larger, the electrostatic force gets smaller at a rapid rate.

19. a.

Distance (r) (cm)	$\frac{1}{r^2}\left(\frac{1}{cm^2}\right)$	F_e (F units)
1.0	1.00	16.0
2.0	0.25	4.0
4.0	0.063	1.0
8.0	0.016	0.5

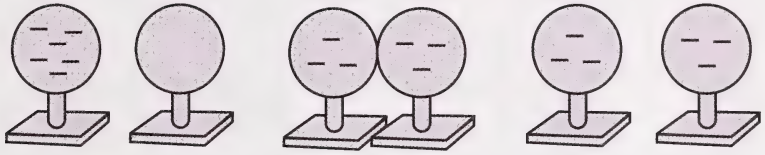
b.



20. The mathematical expression is $F_e \propto \frac{1}{r^2}$. This is an **inverse squared** relationship.

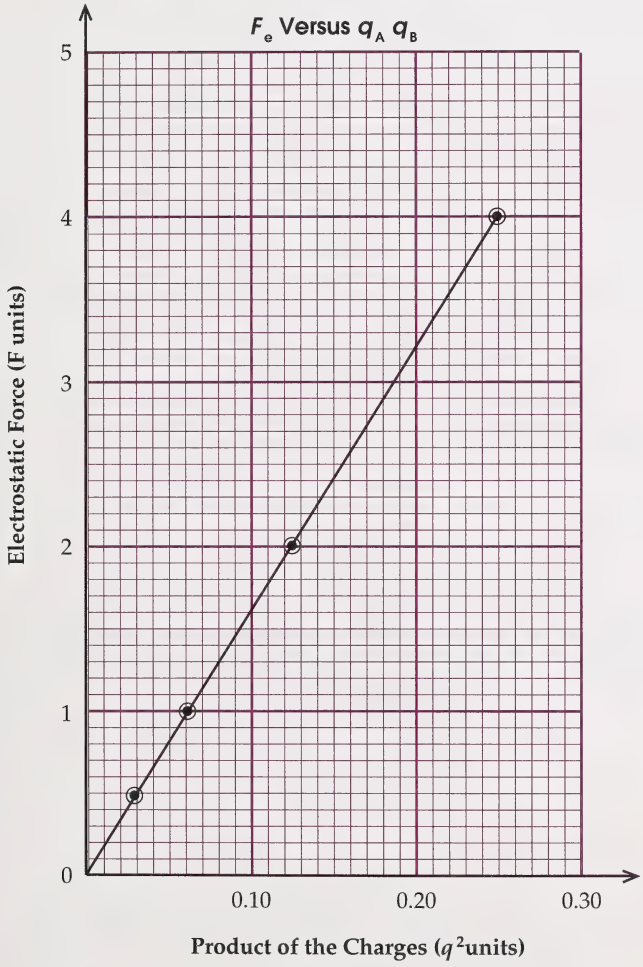
21. Since $F_g \propto \frac{1}{r^2}$ and $F_e \propto \frac{1}{r^2}$, both relationships are the same.

22. Since the spheres are identical when they first touch, the charge will spread out evenly over both due to the mutual repulsion of the charges. This means that each sphere should have the same amount of charge.



When the spheres are separated again, each would have half of the original charge.

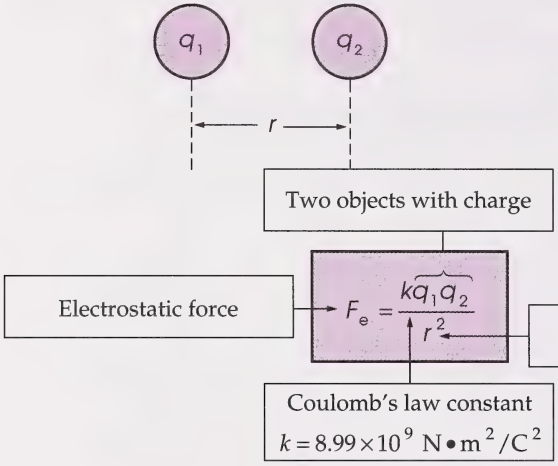
23.



24. The graph is a straight line.

25. This proves that $F_e \propto q_A q_B$.

26. Coulomb's Law



Quantity	Units
F_e	N
k	$\frac{\text{N} \bullet \text{m}^2}{\text{C}^2}$
q	C
r	m

27. a. $q_1 = +1.00\ \text{C}$
$q_2 = +1.00\ \text{C}$
$r = 1.00\ \text{m}$
$F_e = ?$

$$F_e = \frac{kq_1q_2}{r^2}$$
$$= \frac{\left(8.99 \times 10^9\ \text{N} \bullet \text{m}^2/\text{C}^2\right)\left(+1.00\ \text{C}\right)\left(+1.00\ \text{C}\right)}{\left(1.00\ \text{m}\right)^2}$$
$$= 8.99 \times 10^9\ \text{N}\ \text{(3 significant digits)}$$

b. It would be exceptionally difficult to store this much charge on two objects so close together. If a cloud discharges about 1 C in a lightning bolt that can travel over 1 km through the air, it is difficult to imagine how you could put that much charge on each object without it grounding to the nearby equipment. The other difficulty concerns the force that would be required to hold the two objects in position while they repel each other. The force of 9×10^9 N is roughly equivalent to the weight of an object with a mass of 1 million t!

28. a. $q_1 = +4.5 \times 10^{-6}\ \text{C}$
$q_2 = +1.5 \times 10^{-9}\ \text{C}$
$r = 0.45\ \text{m}$

$$F_e = \frac{kq_1q_2}{r^2}$$
$$= \frac{\left(8.99 \times 10^9\ \frac{\text{N} \bullet \text{m}^2}{\text{C}^2}\right)\left(+4.5 \times 10^{-6}\ \text{C}\right)\left(+1.5 \times 10^{-9}\ \text{C}\right)}{\left(0.45\ \text{m}\right)^2}$$
$$= 3.0 \times 10^{-4}\ \text{N}\ \text{(2 significant digits)}$$

b. The positive value for the force indicates that there is a force of repulsion between the balloon and the Van de Graaff generator. This means that the electrostatic force acting on the balloon will tend to push it away from the Van de Graaff generator.

29. **Textbook question 1:**

$q_{\text{nucleus}} = +4.32\times10^{-18}\ \text{C}$

$q_{\text{electron}} = -1.60\times10^{-19}\ \text{C}$

$r = 1.0\times10^{-12}\ \text{m}$

$F_e = ?$

$$F_e = \frac{kq_{\text{nucleus}}q_{\text{electron}}}{r^2}$$

$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\bullet\text{m}^2}{\text{C}^2}\right)\left(+4.32\times10^{-18}\ \text{C}\right)\left(-1.60\times10^{-19}\ \text{C}\right)}{\left(1.0\times10^{-12}\ \text{m}\right)^2}$$

$$= -6.2\times10^{-3}\ \text{N}\ \text{(2 significant digits)}$$

Note that the negative value of this force indicates that it is an attractive force.

30. $$F_e = \frac{kq_{\text{Balloon 1}}q_{\text{Balloon 2}}}{r^2}$$

$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\bullet\text{m}^2}{\text{C}^2}\right)\left(3\times10^{-7}\ \text{C}\right)\left(3\times10^{-7}\ \text{C}\right)}{\left(0.85\ \text{m}\right)^2}$$

$$= 1\times10^{-3}\ \text{N}\ \text{(1 significant digit)}$$

31. The electrostatic force on Balloon 1 is 1×10^{-3} N, left.

32. The electrostatic force on Balloon 2 is 1×10^{-3} N, right.

33. The answers to the two preceding questions illustrate Newton's third law, which states that if object 1 exerts a force on object 2, object 2 will exert an equal but opposite force on object 1.

Section 1: Activity 4

1. The units for electric field are force units divided by charge units, or N/C.

2. $F_e = 3.5\times10^{-4}\ \text{N}$

$q = 9.2\times10^{-9}\ \text{C}$

$|\vec{E}| = ?$

$$|\vec{E}| = \frac{F_e}{q}$$

$$= \frac{\left(3.5\times10^{-4}\ \text{N}\right)}{\left(9.2\times10^{-9}\ \text{C}\right)}$$

$$= 3.8\times10^{4}\ \text{N/C}$$

3. The value for electric field states that for this point in space, each coulomb will experience 3.8×10^{4} N of force. This can also be solved mathematically.

$$|\vec{E}| = \frac{F_e}{q}$$
$$F_e = |\vec{E}|q$$
$$= (3.8\times10^{4}\ \text{N/C})(1.0\ \text{C})$$
$$= 3.8\times10^{4}\ \text{N}$$

4. a. The magnitude of the electric field is influenced by the charge on the source and the distance from the source.

   b. The Coulomb constant is such a large value that even sources with small amounts of charge can produce electric fields with large magnitudes.

5. $q_1 = 4.8\times10^{-7}$ C
   $r = 33.7\ \text{cm} = 0.337\ \text{m}$
   $|\vec{E}| = ?$

$$|\vec{E}| = \frac{kq_1}{r^2}$$
$$= \frac{(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2)(4.8\times10^{-7}\ \text{C})}{(0.337\ \text{m})^2}$$
$$= 3.8\times10^{4}\ \text{N/C}$$

6. a. $r = 5.29\times10^{-11}$ m
   $q_p = +1.60\times10^{-19}$ C
   $|\vec{E}| = ?$

$$|\vec{E}| = \frac{kq_p}{r^2}$$
$$= \frac{(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})}{(5.29\times10^{-11}\ \text{m})^2}$$
$$= 5.14\times10^{11}\ \text{N/C}$$

   b. $|\vec{E}| = 5.14\times10^{11}$ N/C
   $q_e = -1.60\times10^{-19}$ C
   $F_e = ?$

$$|\vec{E}| = \frac{F_e}{q}$$
$$F_e = |\vec{E}|q$$
$$= (5.14\times10^{11}\ \text{N/C})(1.60\times10^{-19}\ \text{C})$$
$$= 8.22\times10^{-8}\ \text{N}$$

The sign of the charge is not substituted into the equation. As was the case with Coulomb's law, the signs are used to determine the direction of the vectors.

c. $q_p = +1.60\times10^{-19}\ \text{C}$

$q_e = -1.60\times10^{-19}\ \text{C}$

$r = 5.29\times10^{-11}\ \text{m}$

$F_e = ?$

$$F_e = \frac{kq_p q_e}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\ \text{C}\right)\left(1.60\times10^{-19}\ \text{C}\right)}{\left(5.29\times10^{-11}\ \text{m}\right)^2}$$

$$= 8.22\times10^{-8}\ \text{N}$$

7. **Textbook question 1:**

$Q = 150\,\mu\text{C} = 1.50\times10^{-4}\ \text{C}$

$r = 65\ \text{cm} = 0.65\ \text{m}$

$k = 8.99\times10^9\ \dfrac{\text{N}\bullet\text{m}^2}{\text{C}^2}$

$$|\vec{E}| = \frac{kQ}{r^2}$$

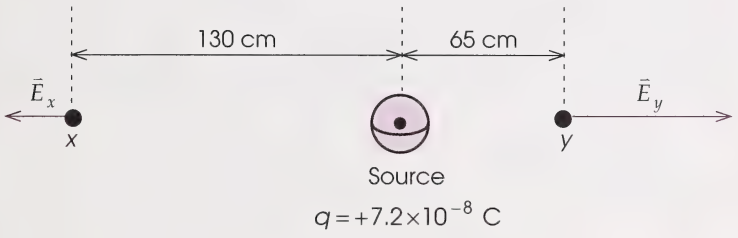
$$= \frac{\left(8.99\times10^9\ \dfrac{\text{N}\bullet\text{m}^2}{\text{C}^2}\right)\left(1.5\times10^{-4}\ \text{C}\right)}{\left(0.65\ \text{m}\right)^2}$$

$$= 3.2\times10^6\ \text{N/C}$$

The electric field around your head is $3.2\times10^6\ \text{N/C}$ in the direction from the sweater toward your head.

Textbook question 2: Your charge is $-150\ \mu\text{C}$ since it must be equal and opposite to the charge on the sweater.

8. a.



$$|\vec{E}_x| = \frac{kq}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(7.2\times10^{-8}\ \text{C}\right)}{\left(1.30\ \text{m}\right)^2}$$

$$= 383\ \text{N/C}$$

$\vec{E}_x = 3.8\times10^2\ \text{N/C}$, away from the source

$\vec{E}_x = 3.8\times10^2\ \text{N/C}$, left

$$|\vec{E}_y| = \frac{kq}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(7.2\times10^{-8}\ \text{C}\right)}{\left(0.65\ \text{m}\right)^2}$$

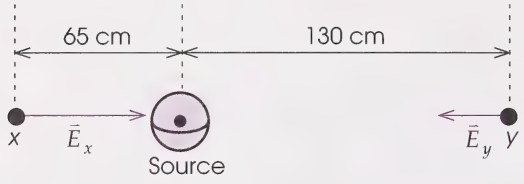
$$= 1.53\times10^3\ \text{N/C}$$

$\vec{E}_y = 1.5\times10^3$ N/C, away from the source

$\vec{E}_y = 1.5\times10^3$ N/C, right

(In both cases a positive test charge would be repelled from the positive source.)

b.



$q = -3.9\times10^{-8}$ C

$$|\vec{E}_x| = \frac{kq}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(3.9\times10^{-8}\ \text{C}\right)}{\left(0.65\ \text{m}\right)^2}$$

$$= 8.3\times10^2\ \text{N/C}$$

$\vec{E}_x = 8.3\times10^2$ N/C, towards the source

$\vec{E}_x = 8.3\times10^2$ N/C, right

$$|\vec{E}_y| = \frac{kq}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(3.9\times10^{-8}\ \text{C}\right)}{\left(1.30\ \text{m}\right)^2}$$

$$= 2.1\times10^2\ \text{N/C}$$

$\vec{E}_y = 2.1\times10^2$ N/C, towards the source

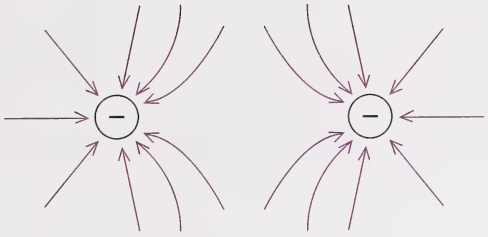
$\vec{E}_y = 2.1\times10^2$ N/C, left

(In both cases a **positive** test charge would be attracted to the negative source.)

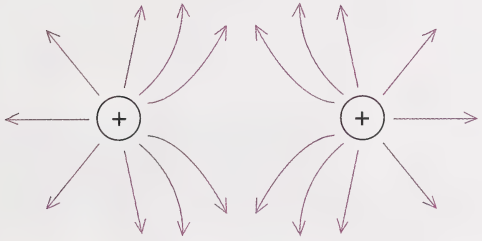
9. The electric field vector will always point away from a positive source because a **positive test charge** will always be repelled from a positive source.

10. The electric field vector will always point towards a negative source because a **positive test charge** will always be attracted to a negative source.

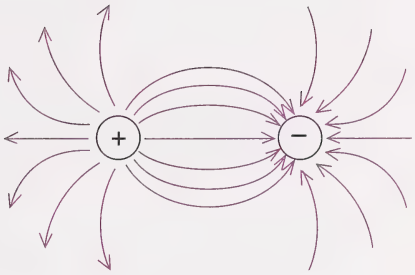
11. a.



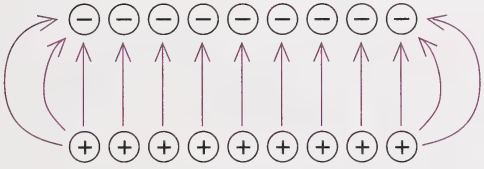
b.



c.

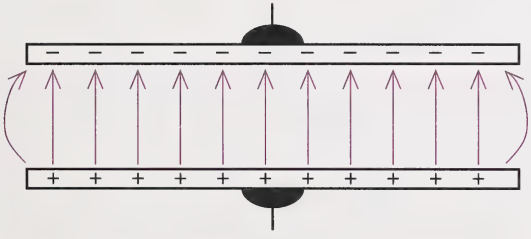


12.



The net effect in the region in the middle is for the field lines to run parallel to each other. The reason is that the horizontal components of one charge's electric field lines are cancelled by the horizontal components of another. The only place that this does not occur is on the edges where there are no charges left on the outside to cancel the horizontal components.

13.



The reasoning behind this answer is identical to that used to answer the preceding question.

Section 1: Activity 5

1. Magnetic rocks were used for navigation 2000 years ago.

2. a. You might have named substances such as iron, nickel, or cobalt.

   b. Answers may vary, but you may have predicted that magnetic properties are due to the structure of the atom, which in turn is a consequence of the behaviour of the electrons within the atom.

3. Electric energy is converted into mechanical energy.

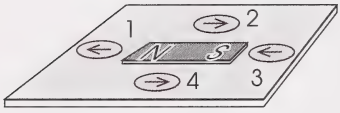
4. Answers may vary. You may have listed any of these types of research or others:

   - examining the relationship between migrating birds and Earth's magnetic field
   - comparing the behaviours of organisms living near the North Pole and South Pole of Earth
   - testing the growth of unicellular plants and animals in strong magnetic fields

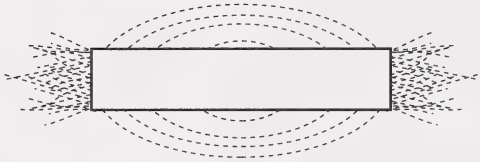
5. a. It is important to study and understand the concepts of magnetism because new applications may be found and applied in modern science.

   b. There are many correct answers to this question. You may have listed the following four uses or others:

   - electric devices
   - navigation
   - electromagnetic devices
   - new technology

6. 

The north pole of the compass points away from the north pole, or towards the south pole, of the bar magnet.

7. 

The iron filings are most concentrated at the two poles and form arcs between the poles.

8. The field lines do not overlap because the iron filings try to line up in separate lines.

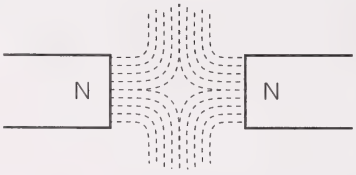
9. The magnetic flux is greatest at the poles because that is where the greatest concentration of magnetic field lines exists.

10. The iron filings stand up on the paper.

11. The magnetic field must be three-dimensional because the iron filings stand up and form a thee-dimensional pattern.

12. When the two north poles are moved towards each other, the magnets push apart, or repel.

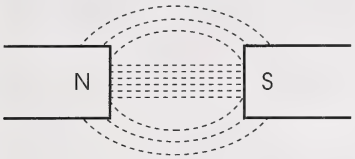
13. When the two south poles are moved towards each other, the magnets push apart, or repel.

14. 

Your sketch should look like the one that is shown. The field lines of one north pole bend away from the field lines of the other. They repel each other.

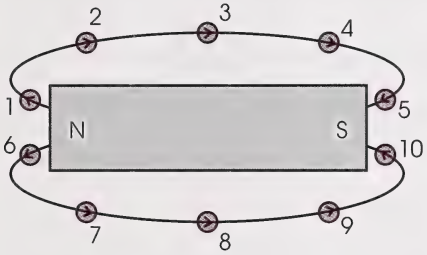
15. When the north and south poles of the magnets are moved towards each other, they are attracted to each other.

16. The two kinds of magnetic forces are attractive and repulsive.

17. 

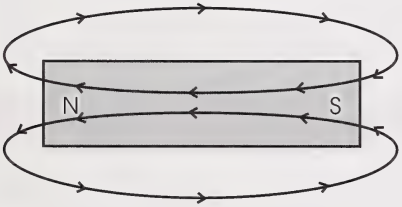
Your sketch should look like the one that is shown. The field lines run from the pole of one magnet to the opposite pole of the other magnet.

18. The north pole of the compass points away from the north pole of the bar magnet.

19. 

The direction of the magnetic field is away from the north pole of a magnet and towards the south pole.

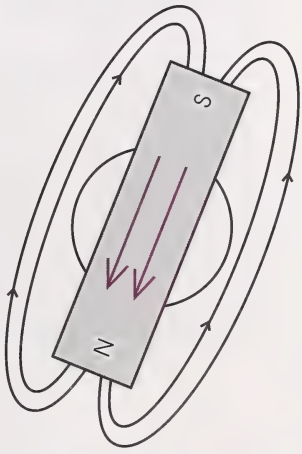
20. The north pole of the compass points towards the north pole of the bar magnet.

21. 

The direction of the magnetic field lines outside a bar magnet is from north to south. Inside the bar magnet the magnetic field lines are from south to north.

22. The alignment of iron filings and the compass needle are the same, or parallel to each other.

23. There is no net force acting on the compass needle because it no longer deflects. There are many forces acting, magnetic and gravitational to mention two, but because the compass needle has no acceleration, the forces must balance. This is in accordance with Newton's second law, which says that when a net force acts on an object, the object will accelerate in the direction of the net force.

24. 

25. The **magnetic south** pole of the imaginary magnet inside Earth lies under the **geographic north** pole of the plant. Recall from the previous exercise that the coloured end of the compass needle points to the south pole of a bar magnet. When people say that the extreme northern parts of Canada are close to the North Pole, they are referring to the geographic North Pole of Earth.

26. The word *lodestone* is derived from a word that originally meant leading stone. This is because the lodestone can lead the way by showing the right direction.

27. Magnetic declination refers to the amount that Earth's magnetic field line differs from the north geographic pole of Earth. This measurement is made in the horizontal plane. Magnetic inclination refers to the angle that Earth's magnetic field line makes with a line perfectly horizontal to Earth's surface. This measurement is made in the vertical plane.

28. These bacteria would die because they would come to the surface of the mud.

29. The pigeon would fly in circles due to having a strong magnetic field continually on the side of one wing. This would produce a turning effect.

30. Whales use magnetic field strength contours for migration purposes.

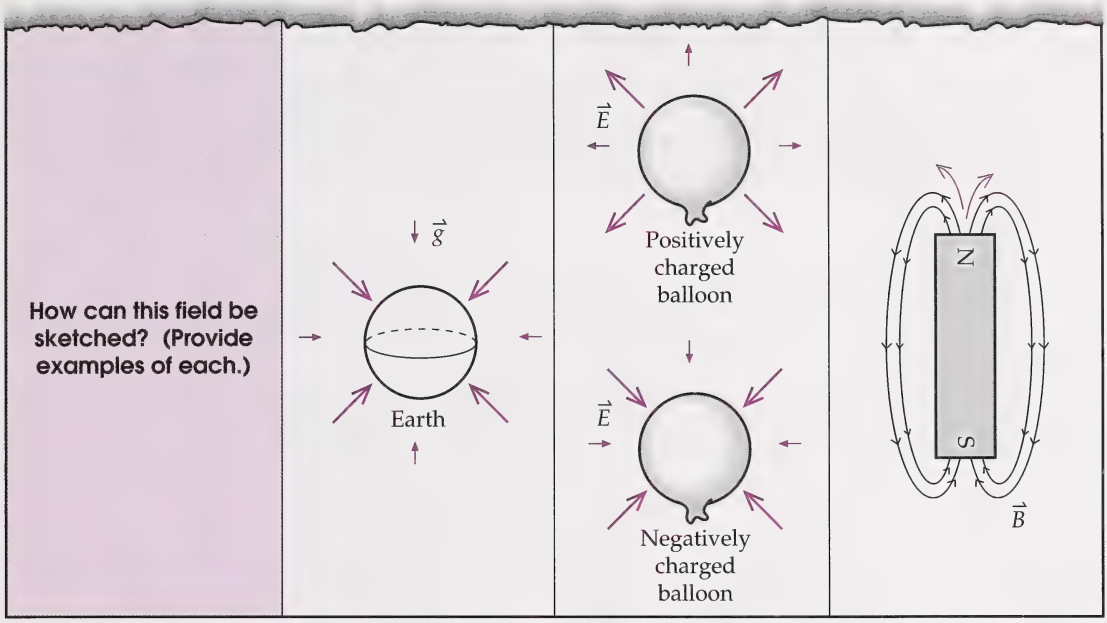
31. There would no longer be protection from the solar wind, so radio, television, and telecommunications signals would be disrupted. In addition severe storms, like those observed on Venus, might occur.

Section 1: Follow-up Activities

Extra Help

1.

Characteristic of Field	Gravitational	Electric	Magnetic
What is the source or origin of this field?	a mass	a charge	a moving charge
What determines the direction of this field?	the direction of the gravitational force on a test mass	the direction of the electrostatic force on a positive test charge	the direction of magnetic force on the north end of a compass needle
Can this field exert both attractive and repulsive forces?	attractive only	attractive and repulsive	attractive and repulsive
How does the force exerted by the field change as the distance from the source increases?	decreases	decreases	decreases



2. a. When a piece of lodestone was suspended with a string, it pointed in a north-south direction. Using lodestone as a simple compass led to an advancement in sea exploration.

   b. When iron filings were sprinkled around a lodestone sphere, they arranged themselves in lines that were concentrated at the poles.

   c. The arrangement of iron filings around a bar magnet on Earth has a two-dimensional pattern. In space the iron filings illustrate a three-dimensional pattern. Because there is no friction between the iron filings and paper in space, they are attracted towards the poles.

   d. Gilbert had concluded that the south magnetic pole is located in the northern hemisphere because the north pole of a compass is attracted to the opposite pole of Earth's magnetic field, or the south pole.

   e. When a bar magnet is heated, it loses its magnetic properties.

   f. Earth's magnetic field is believed to be the result of electrically charged iron rotating relative to Earth's mantle.

   g. The term *magnetic declination* is the angle between the geographic north pole and the magnetic north pole.

   h. The magnetic declination in Toronto is 9° W of N.

   i. The magnetic field line would be parallel to Earth's surface at the equator.

   j. The term given to the angle between Earth's surface and the field lines is the *angle of inclination*.

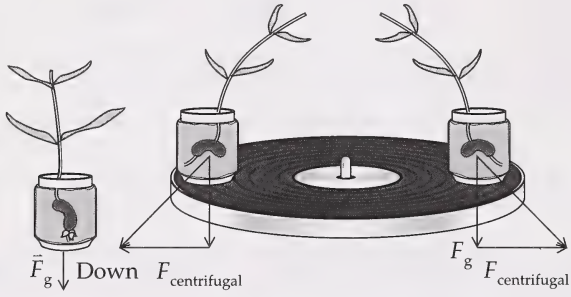
k. A dip needle is used to measure the angle of inclination at various positions above Earth's surface. When the dip needle is over the north magnetic pole, it would be perpendicular to Earth's surface.

l. Compass navigation in the Arctic would not be very accurate because the compass would point downwards towards Earth's surface over the magnetic pole. More reliable means of navigation could include the global positioning systems (GPS). Such systems involve satellite communications that give latitude and longitude. During the day the sun could also be used for navigation.

Enrichment

1. a. From the frame of reference of the stationary bean, gravity provides the root with a positive geotropism and it grows down. In other words, the root grows in the direction of the force acting on it. In a similar way, gravity provides the stems with a negative geotropism, and so the stems grow up.

In the frame of reference of the rotating bean, gravity and the centrifugal force combine to give the illusion that down is now at a new angle. The roots in the rotating frame will grow in the direction of the net force, while the stems will grow in the opposite direction.



b.

Notice that the stems grew in towards the centre of the turntable (in the opposite direction of the roots) since they grew in a negative geotropism. The roots are shorter and it is more difficult to discern which direction they are actually growing in.

c. Refer to the answer for 1. a.

2. **Textbook question 11:** Magnetic declination is the difference between the direction to the magnetic north pole and the direction to the geographic north pole. Magnetic inclination, on the other hand, is the slope of Earth's magnetic field lines relative to the surface of Earth.

Textbook question 12: The fact that the inclination of the magnetic field is steep even as far south as Lethbridge indicates that the magnetic field must originate deep within the Earth.

Textbook question 1:

$$m_M = 6.42 \times 10^{23} \text{ kg}$$
$$r_M = 3394 \text{ km}$$
$$= 3.394 \times 10^6 \text{ m}$$

$$g = \frac{Gm_M}{r_M^2}$$
$$= \frac{\left(6.67 \times 10^{-11} \frac{\text{N} \bullet \text{m}^2}{\text{kg}^2}\right)\left(6.42 \times 10^{23} \text{ kg}\right)}{\left(3.394 \times 10^6 \text{ m}\right)^2}$$
$$= 3.72 \frac{\text{N}}{\text{kg}}$$

The value of g on Mars is approximately 3.72 N/kg.

Textbook question 6: The electric field between the plates is uniform; therefore, the force on the proton would not change.

Textbook question 7: Canada is a country that spans a considerable range of latitude and longitude. In the polar regions the magnetic field lines are nearly vertical and therefore have a high inclination. The magnetic field lines also converge toward the magnetic pole which is situated in the Canadian Arctic at about 80°N latitude and along about the midline of the continent.

Section 2: Activity 1

1. Many people use electric lights, digital clock radios, toasters, kettles or coffee makers, telephones, and electric thermostats on a daily basis.

2. If an electron is to move around an electric circuit, an electric force must act on it. The electric force acts on the electrons through the action of the electric field.

3. The charged spheres would not be a good source of charge flow because the charge would flow for only an instant, until the spheres were neutralized. Most applications of electric current require the current to flow for a sustained period of time.

4. a. This is the graphite rod that acts as the positive electrode.

   b. This is the zinc outer case that acts as the negative electrode.

   c. This is the chemical compound inside the battery that removes electrons from the graphite rod.

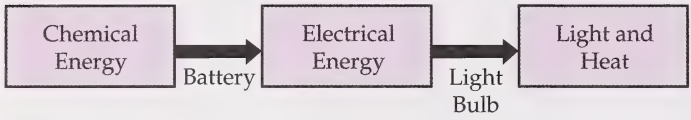
5. The flashlight battery can sustain the current for a period of time.

6. The continuous flow of charge is called current electricity.

7. a. The battery is a source of electrical energy.

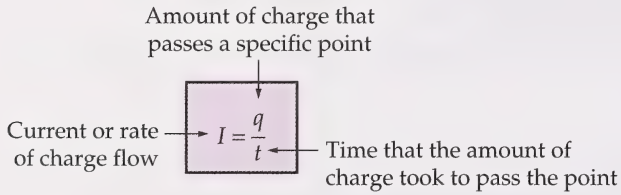
   b. The connecting wires allow the current to flow from the negative electrode to the load and then from the load back to the positive electrode.

   c. The light bulb acts as a load and it uses the energy provided by the source.

8. 

9. Direct current involves the electrons flowing in only one direction around the circuit, while with alternating current the electrons periodically change directions. Direct current is what a flashlight battery provides while wall outlets in people's houses provide alternating current.

10. No, there is no difference in the number of electrons passing each point. In this circuit there is only one closed path for electrons to follow. If the number of electrons was different, then the electrons would pile up at one place and would run out at another, which would mean that the circuit could no longer operate.

11. 
Amount of charge that passes a specific point
Current or rate of charge flow
$I = \frac{q}{t}$
Time that the amount of charge took to pass the point

12. $1\,A = \frac{1\,C}{1\,s}$ where A is ampere, C is coulomb and s is second.

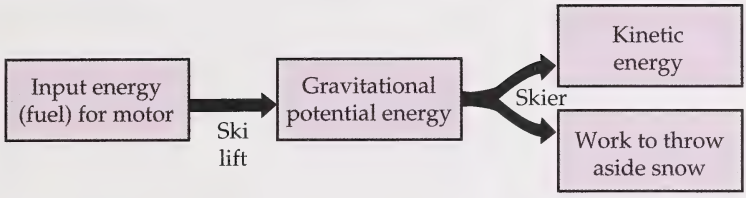
13. The skier's gravitational potential energy increases from Point C to Point D. This increase in energy comes from the motor of the ski lift.

14. The skier has the most gravitational potential energy when in the highest position relative to the bottom of the ski hill. This occurs at Points D and A.

15. The skier has the least gravitational potential energy when at the bottom of the ski hill. This corresponds to Points B and C.

16. As the skier travels from Point A to Point B gravitational potential energy is converted to kinetic energy used in moving the skier downhill and to do work throwing aside snow from the sides of the skis. It is also worth noting that at high speeds, air resistance is an important variable because work must also be done to move air around the skier's body.

17.



18. The flashlight battery corresponds to the ski lift.

19. The heating element corresponds to the ski slope.

20. Each coulomb of charge corresponds to one skier.

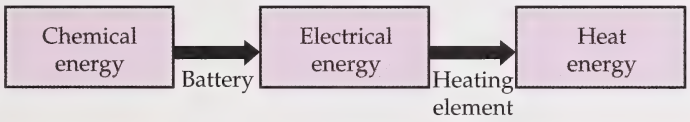
21. The electric potential energy of a coulomb is increased between Points C and D. This increased energy comes from the chemical energy released by the compounds within the battery.

22. A coulomb will have the most electric potential energy at Points D and A. If the wires are good conductors, no energy should be lost as coulombs travel from Point D to Point A.

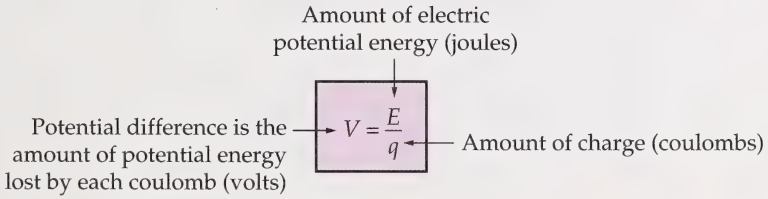
23. A coulomb will have the least electric potential energy at Points B and C. If the wires are good conductors, the charges will not lose any more energy travelling from Point B to Point C.

24. As a coulomb passes from Point A to Point B, electric potential energy is converted to heat energy.

25.



26.


Amount of electric potential energy (joules)
Potential difference is the amount of potential energy lost by each coulomb (volts)
$V = \frac{E}{q}$
Amount of charge (coulombs)

27. There is no potential difference across Points D and A because there is no difference in the energy possessed by a coulomb passing by Point D compared to that same coulomb passing by Point A. The same reasoning applies to Points B and C.

28. The potential difference decreases across Points A and B because the charges lose energy as they pass between these points.

29. The potential difference increases across Points C and D because the charges gain energy as they pass between these points.

30. a. $|\vec{E}| = 3.85\times10^{3}\ \text{N/C}$

$d = 10.5\ \text{cm}$

$= 0.105\ \text{m}$

$V = ?$

$$V = |\vec{E}|d$$
$$= \left(3.85\times10^{3}\ \frac{\text{N}}{\text{C}}\right)(0.105\ \text{m})$$
$$= 404.25\frac{\text{N}\bullet\text{m}}{\text{C}}$$
$$= 404\frac{\text{J}}{\text{C}}$$
$$= 404\ V$$

Note the way that the units eventually give volts in this question. A joule is 1 N • M and a joule/coulomb is 1 volt (V).

b. $V = 404\ V = 404\frac{\text{J}}{\text{C}}$

$q = 5.2\times10^{-6}\ \text{C}$

$E_e = ?$

$$E_e = Vq$$
$$= \left(404\frac{\text{J}}{\text{C}}\right)\left(5.2\times10^{-6}\ \text{C}\right)$$
$$= 2.1\times10^{-3}\ \text{J}$$

c. $E_e = 2.1\times10^{-3}\ \text{J}$

$m = 7.95\times10^{-5}\ \text{kg}$

$v = ?$

$$E_k = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$= \sqrt{\frac{2\left(2.1\times10^{-3}\ \text{J}\right)}{\left(7.95\times10^{-5}\ \text{kg}\right)}}$$
$$= \sqrt{52.830\frac{\text{m}^2}{\text{s}^2}}$$
$$= 7.3\ \text{m/s}$$

31. **Textbook question 1:**

$q_e = 1.6\times10^{-19}\ \text{C}$

$V = 26\ \text{kV}$

$= 2.6\times10^{4}\ \text{V}$

$d = 20\ \text{cm}$

$= 0.20\ \text{m}$

$|\vec{E}| = ?$

$$V = |\vec{E}|d$$
$$|\vec{E}| = \frac{V}{d}$$
$$= \frac{\left(2.6\times10^{4}\ \text{V}\right)}{0.20\ \text{m}}$$
$$= 1.3\times10^{5}\ \frac{\text{N}}{\text{C}}$$

Refer to the Example on page 262 of your textbook to see how the units reduce for this type of question.

Textbook question 2:

$V = 2.6 \times 10^4 \text{ V}$

$q = 1.6 \times 10^{-19} \text{ C}$

$E_e = ?$

The electric energy is the source for the gain in kinetic energy. Therefore:

$$\begin{aligned} E_k &= E_e \\ &= Vq \\ &= \left(2.6 \times 10^4 \text{ V}\right)\left(1.6 \times 10^{-19} \text{ C}\right) \\ &= 4.2 \times 10^{-15} \text{ J} \end{aligned}$$

Textbook question 3:

$E_k = 4.2 \times 10^{-15} \text{ J}$

$m = 9.11 \times 10^{-31} \text{ kg}$

$v = ?$

$$E_k = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E_k}{m}}$$

$$= \sqrt{\frac{2\left(4.2 \times 10^{-15} \text{ J}\right)}{9.11 \times 10^{-3} \text{ kg}}}$$

$$= \sqrt{9.221 \times 10^{15} \frac{\text{m}^2}{\text{s}^2}}$$

$$= 9.6 \times 10^7 \text{ m/s}$$

Note that this speed is very close to the speed of light, 3.00×10^8 m/s. This means that simplifications were made in the solution to this problem because when objects reach speeds this close to the speed of light, the effects of Einstein's relativity theory begin to influence the equations and therefore the answers.

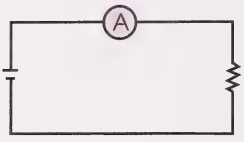
Section 2: Activity 2

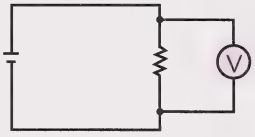
1. No, the electrons will not move in the same direction as the electric field. The direction of an electric field is the same as the direction of the electric force on a positive test charge. Since electrons are negative they will be forced in the opposite direction to the electric field.

2. a. Circuit B shows two resistors connected in series because there is only one path or a single loop for electrons to travel in this circuit.

   b. Circuit A shows two resistors connected in parallel because there is more than one path for electrons to travel in this circuit. The electrons can either branch and travel through Resistor 1 or Resistor 2.

3. Since a resistor hinders the flow of electrons, you could also say that it **resists** the flow of electrons.

4. 

5. 

6. You should use the 4.34 V value because that is what the actual potential difference (voltage) is. The 4.5 V marking is a rough scale on the power supply.

7. a. When measuring the current, the multimeter should make a series connection with the resistor. Also the positive lead should be moved into the input for measuring current.

   b. When measuring the current, the multimeter should make a series connection with the resistor.

   c. There is no current because there must be a break or bad contact somewhere in the circuit. It could also mean that the fuse has blown.

   d. The multimeter has to be connected across the resistor (making a parallel connection). Also the positive lead is not plugged into the voltmeter section.

   e. The polarity of the connection is reversed. The negative lead connected to the negative output of the power supply should be connected to the COM plug.

8. You should always double check the setting of the dial on the meter, the position of the input leads, and whether the circuit has the meter connected in series or parallel.

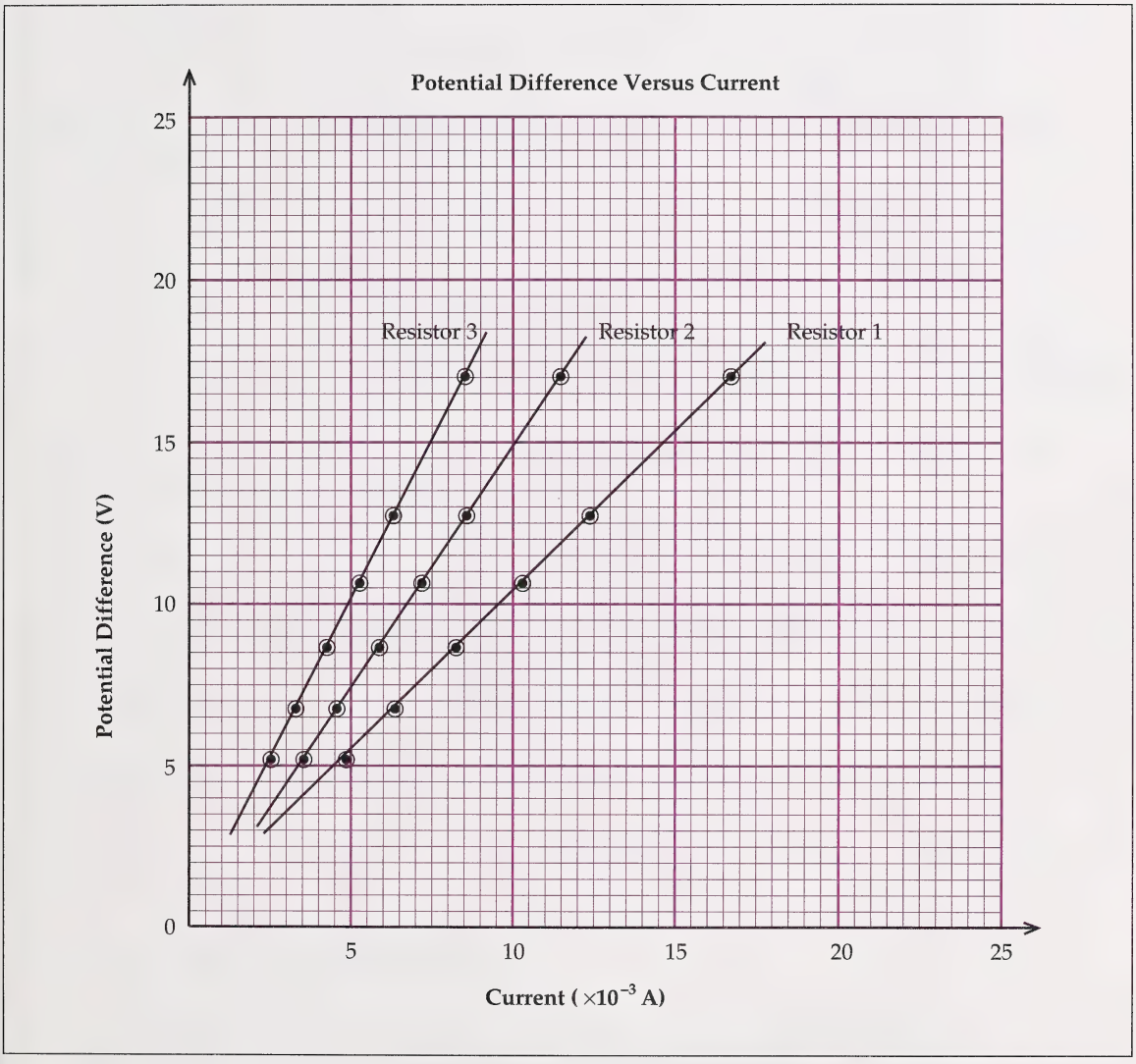
9. The following are data charts like those you should have copied into your notebook. The values are sample values. Your values may differ from those shown, but the trends should be the same.

Resistor 1	
V (volts)	I $(\times 10^{-3}\ A)$
5.1	4.9
6.7	6.5
8.7	8.4
10.6	10.3
12.7	12.4
17.1	16.7

Resistor 2	
V (volts)	I $(\times 10^{-3}\ A)$
5.1	3.4
6.7	4.5
8.7	5.8
10.6	7.1
12.7	8.5
17.1	11.4

Resistor 3	
V (volts)	I $(\times 10^{-3}\ A)$
5.1	2.5
6.7	3.3
8.7	4.3
10.6	5.2
12.7	6.3
17.1	8.6

10. a. The following graph contains the answers for parts a. and b. of questions 10 through 12.



b. This question is answered on the previous graph.

c. $$\text{slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{15.8\ \text{V} - 9.0\ \text{V}}{15.5\ \text{mA} - 8.75\ \text{mA}}$$
$$= \frac{6.8\ \text{V}}{6.75\ \text{mA}}$$
$$= \frac{6.8\ \text{V}}{6.75 \times 10^{-3}\ \text{A}}$$
$$= 1007\ \text{V/A}$$
$$= 1.0 \times 10^{3}\ \text{V/A}$$

11. a. This question is answered on the previous graph.

b. This question is answered on the previous graph.

c. $$\text{slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{17.8\ \text{V} - 4.0\ \text{V}}{12.0 \times 10^{-3}\ \text{A} - 2.75 \times 10^{-3}\ \text{A}}$$
$$= \frac{13.8\ \text{V}}{9.25 \times 10^{-3}\ \text{A}}$$
$$= 1492\ \text{V/A}$$
$$= 1.5 \times 10^{3}\ \text{V/A}$$

12. a. This question is answered on the previous graph.

b. This question is answered on the previous graph.

c. $$\text{slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{17.5\ \text{V} - 5.0\ \text{V}}{8.75 \times 10^{-3}\ \text{A} - 2.5 \times 10^{-3}\ \text{A}}$$
$$= \frac{12.5\ \text{V}}{6.25 \times 10^{-3}\ \text{A}}$$
$$= 2000\ \text{V/A}$$
$$= 2.0 \times 10^{3}\ \text{V/A}$$

13. The resistors had the following values:

- $R_1 = 1007\ \Omega$
- $R_2 = 1492\ \Omega$
- $R_3 = 2000\ \Omega$

14. The relationship between the potential difference and the current is that they are directly proportional. According to the graph, it is a straight line. Therefore,

$$y = mx + b$$

Slope

y-intercept: For these graphs the y-intercept is very close to zero in each case. This makes sense because if the current has a zero value, there is no reason for charges to flow because there is no potential difference. If the y-intercept is assumed to be zero, the equation simplifies as shown.

By inspection

$$y = mx + b$$

$$V = RI + 0$$

$$V = RI$$

15. a. The copper ions can vibrate but they cannot leave their positions within the network. The free electrons are loosely held and can drift about between the ions with relative ease.

b. The free electrons would move to the positive end of the copper conductor due to the electric field exerting a force on them.

c. The potential difference is approximately zero because there is little resistance to electron flow in the copper wire.

16. a. There are fewer free electrons because some of the electrons are involved in forming bonds between the metal ions.

b. A greater potential difference is required because there are fewer free electrons and because the bonds restrict the pathways between the ions.

c. The temperature increases because some of the electrons collide with the ions causing them to increase their rate of vibration. Since temperature relates to the average kinetic energy of the ions in the network, the temperature increases due to the increased vibrational energy.

d. The structure of the heating element is such that the movement of electrons is impeded causing more collisions between electrons and the ions than in the copper conductor.

17. No, the resistance value does not change when the resistor is connected to a different circuit. Resistance is a property of the material that comprises the resistor itself. The following values for a 15 Ω resistor help to make this point.

Trial 1: $V = 15\,\text{V}$
$I = 1\,\text{A}$
$R = ?$

$$R = \frac{V}{I}$$
$$= \frac{15\,\text{V}}{1\,\text{A}}$$
$$= 15\frac{\text{V}}{\text{A}}$$
$$= 15\,\Omega$$

Trial 2: $V = 1.5\,\text{V}$
$I = 0.10\,\text{A}$
$R = ?$

$$R = \frac{V}{I}$$
$$= \frac{1.5\,\text{V}}{0.10\,\text{A}}$$
$$= 15\frac{\text{V}}{\text{A}}$$
$$= 15\,\Omega$$

18. a. If a large potential difference existed across two different parts of your body, then it's possible that a dangerous current could flow through your body. Even small currents can be dangerous. A current of only 0.01 A or 10 mA can cause convulsions, while a current of 0.1 A or 100 mA can cause death. Note: 1 ampere (A) = 1000 milliamperes (mA).

b. There is low resistance and thus a low potential difference in the wire between the bird's feet. This low potential difference is not enough to allow a current to flow through the high resistance of the bird's feet and body but is enough to allow the current to flow in the wire.

19. a. $V = 40\,\text{V}$
$R = 1.0 \times 10^5\,\Omega$
$I = ?$

$$V = IR$$
$$I = \frac{V}{R}$$
$$= \frac{40\,\text{V}}{1.0 \times 10^5\,\Omega}$$
$$= 0.00040\,\text{A}$$
$$= 0.40\,\text{mA}$$

b. $V = 40\,\text{V}$
$R = 1500\,\Omega$
$I = ?$

$$V = IR$$
$$I = \frac{V}{R}$$
$$= \frac{40\,\text{V}}{1500\,\Omega}$$
$$= 0.027\,\text{A}$$
$$= 27\,\text{mA}$$

20. a. The potential difference would be 120 V.

b. $V = 120\,\text{V}$
$R = 1500\,\Omega$
$I = ?$

$$V = IR$$
$$I = \frac{V}{R}$$
$$= \frac{120\,\text{V}}{1500\,\Omega}$$
$$= 0.0800\,\text{A}$$
$$= 80.0\,\text{mA}$$

c. The likely effect of this amount of current is respiratory paralysis.

d. Bathrooms are locations where people have many parts of the body wet due to washing or taking a shower. This means that the body's resistance is low, which could result in the flow of a dangerous amount of current.

21. $I = 20\,\text{mA}$
$= 0.020\,\text{A}$
$R = 1.0 \times 10^5\ \Omega$
$V = ?$

$$V = IR$$
$$= (0.020\,A)\left(1.0 \times 10^5\ \Omega\right)$$
$$= 2.0 \times 10^3\ \text{V}$$

22. a. $V = 220\,\text{V}$
$I = 20\,\text{mA to } 100\,\text{mA}$
$= 0.020\,\text{A to } 0.100\,\text{A}$
$R = ?$

$$V = IR$$
$$R = \frac{V}{I}$$

For the low current value: $R = \frac{220\,\text{V}}{0.020\,\text{A}}$
$$= 1.1 \times 10^4\ \Omega$$

For the high current value: $R = \frac{220\,\text{V}}{0.100\,\text{A}}$
$$= 2.2 \times 10^3\ \Omega$$

b. Since these resistance values are closer to the 1500 Ω value for wet hands than the $1.0 \times 10^5\ \Omega$ value for dry hands, it is likely that the hands had a significant amount of moisture on them.

23. When wires carry a high current they can overheat to the point that they can cause surrounding materials to catch on fire.

24. a. Since this device delivers a high current to the body of the patient, it presents a hazard to the others in the room. If they were in contact with the patient, the current could travel through them as well.

b. It only takes 10 to 20 mA of current to cause noticeable muscular effects. Since this device delivers up to 49 A for a brief time interval, it is reasonable to assume that the muscular effects would occur on a much larger scale.

25. $V = 100\,\text{V}$
$I = 6\,\text{mA}$
$= 0.006\,\text{A}$
$R = ?$

$V = IR$
$R = \frac{V}{I}$
$= \frac{100\,\text{V}}{0.006\,\text{A}}$
$= 2 \times 10^4\ \Omega$

This value for resistance is closer to the 1500 Ω value for wet hands than the $1.0 \times 10^5\ \Omega$ value for dry hands.

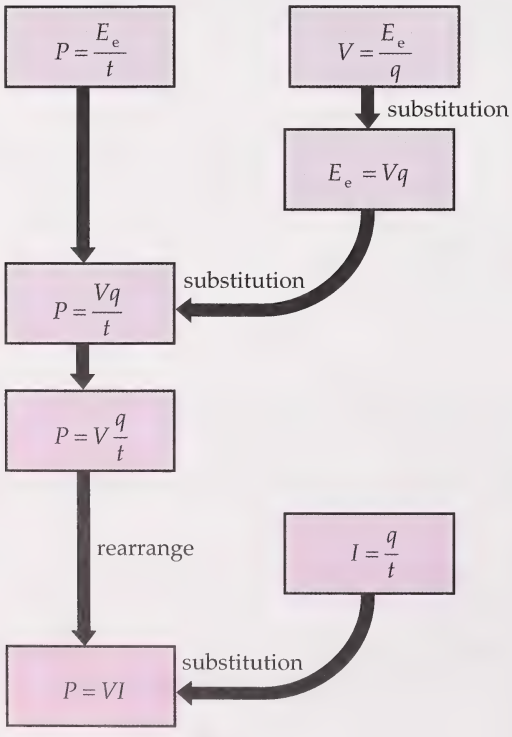
26. a. $P = 800\,\text{W}$
$= 0.800\,kW$
$t = 2.0\,\text{h} \times 7 = 14\,\text{h}$
$E_e = ?$

$E_e = Pt$
$= (0.800\,\text{kW})(14\,\text{h})$
$= 11\,\text{kW} \bullet \text{h}$

b. $P = 800W$
$= 800\frac{\text{J}}{\text{s}}$
$t = 2.0\,\text{h} \times 7 = 14\,\text{h}$
$= 5.04 \times 10^4\ \text{s}$

$E_e = Pt$
$= \left(800\frac{\text{J}}{\text{s}}\right)\left(5.04 \times 10^4\ \text{s}\right)$
$= 4.0 \times 10^7\ \text{J}$

27.



28. **Textbook question 1:**

$I = 13\,\text{A}$

$V = 110\,\text{V}$

$t = 2\,\text{h}$

$\text{rate} = \$0.07/\text{kW} \bullet \text{h}$

$\text{cost} = ?$

Step 1: Calculate the power consumption.

$$P = IV$$
$$= (13\,\text{A})(110\,\text{V})$$
$$= 1430\,\text{W}$$
$$= 1.43\,\text{kW}$$

Step 2: Calculate the energy used.

$$E_e = Pt$$
$$= (1.43\,\text{kW})(2\,\text{h})$$
$$= 2.86\,\text{kWh}$$

Step 3: Calculate the cost.

$$\text{cost} = (2.86\text{kW} \bullet \text{h})\left(\frac{\$0.07}{\text{kW} \bullet \text{h}}\right)$$
$$= \$0.20$$

The cost to sand the floor for 2 hours is $0.20. Note that this question is based on data with only one significant digit. However, extra digits were kept in steps 1 and 2 and two digits were used to express the answer since it involves money which is rounded to the nearest cent.

Textbook question 2:

$$P = 2\,\text{HP} \times \left[\frac{746\text{W}}{\text{HP}}\right] = 1492\,\text{W}$$
$$= 1.492\,\text{kW}$$

$t = 30\,\text{min} = 0.50\,\text{h}$

$\text{rate} = \$0.07/\text{kW} \bullet \text{h}$

$\text{cost} = ?$

Step 1: Calculate the energy used.

$$E_e = Pt$$
$$= (1.492\,\text{kW})(0.50\,\text{h})$$
$$= 0.746\,\text{kW} \bullet \text{h}$$

Step 2: Calculate the cost.

$$\text{cost} = (0.746\,\text{kW} \bullet \text{h})\left(\frac{\$0.07}{\text{kW} \bullet \text{h}}\right)$$
$$= \$0.05$$

The cost to run the vacuum cleaner is $0.05.

Textbook question 3:

$V = 220\,\text{V}$

$I = 40\,\text{A}$

$t = 10\,\text{min} + 45\,\text{min} = 55\,\text{min}$

$= 0.91\overline{6}\,\text{h}$

$\text{rate} = \$0.07/\text{kW} \bullet \text{h}$

$\text{cost} = ?$

Step 1: Calculate the power consumption.

$$P = IV$$
$$= (40\,\text{A})(220\,\text{V})$$
$$= 8800\,\text{W}$$
$$= 8.8\,\text{kW}$$

Step 2: Calculate the energy used.

$$E_e = Pt$$
$$= (8.8\,\text{kW})\left(0.91\overline{6}\,\text{h}\right)$$
$$= 8.0\overline{6}\,\text{kW} \bullet \text{h}$$

Step 3: Calculate the cost.

$$\text{cost} = \left(8.0\overline{6}\,\text{kW} \bullet \text{h}\right)\left(\frac{\$0.07}{\text{kW} \bullet \text{h}}\right)$$
$$= \$0.56$$

The cost of baking the cake is $0.56.

Textbook question 4:

$P = 2500\,\text{W}$

$$= 2500\frac{\text{J}}{\text{s}}$$

$$t = 1\ \text{week} \times \left[\frac{7\,\text{d}}{1\ \text{week}}\right] \times \left[\frac{24\,\text{h}}{1\,\text{d}}\right] \times \left[\frac{60\ \text{min}}{1\,\text{h}}\right] \times \left[\frac{60\ \text{s}}{1\ \text{min}}\right]$$

$$= 6.048 \times 10^5\ \text{s}$$

$\text{rate} = \$0.07/\text{kW} \bullet \text{h}$

$\text{cost} = ?$

Step 1: Calculate the energy used.

$$E_e = Pt$$
$$= \left(2500\frac{\text{J}}{\text{s}}\right)\left(6.048 \times 10^5\ \text{s}\right)$$
$$= 1.51 \times 10^9\ \text{J}$$
$$= 1.51\,\text{GJ}$$

Step 2: Calculate the cost.

$$\begin{aligned}\text{cost} &= (1.51\,\text{GJ})(\$20/\text{GJ}) \\ &= \$30\end{aligned}$$

The cost to run the space heater for one week is $30.

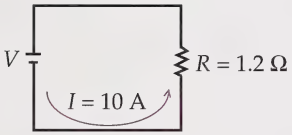
29. a. $R = 15\,\Omega$
$I = 80\,\text{A}$
$P = ?$

$$\begin{aligned}P &= I^2 R \\ &= (8.0\,\text{A})^2\,(15\,\Omega) \\ &= \left(64\,\text{A}^{\cancel{2}}\right)\left(15\frac{\text{V}}{\cancel{\text{A}}}\right) \\ &= 960\,\text{V}\bullet\text{A} \\ &= 960\,\text{W}\end{aligned}$$

b. The toaster would release 960 J of thermal energy in 1 s.

30. The fact that the current is squared accounts for the fact doubling the current causes the thermal energy to increase fourfold.

31. a.



b. $I = 10\,\text{A}$
$R = 1.2\,\Omega$
$P = ?$
$E_e = ?$

Step 1: Calculate the power.

$$\begin{aligned}P &= I^2 R \\ &= (10\,\text{A})^2\,(1.2\,\Omega) \\ &= \left(100\,\text{A}^{\cancel{2}}\right)\left(1.2\frac{\text{V}}{\cancel{\text{A}}}\right) \\ &= 120\,\text{V}\bullet\text{A} \\ &= 120\,\text{W}\end{aligned}$$

The rear window defroster would release 120 J in 1 s.

c. If a short occurred in the circuit, causing more current to be drawn, the 30 A fuse would allow 30 A of current to be drawn before the fuse burned out. Given that the original circuit was protected by a 20 A fuse, this means that the replacement fuse would allow 50% more current to flow than the circuit was designed to handle. This increase in current will have a significant increase in the thermal energy produced because current is squared in the equation $P = I^2 R$. This could result in a fire somewhere along the wires leading to the defroster.

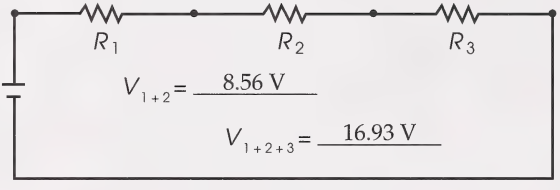
Section 2: Activity 3

1. The following is a sample data chart like the one that you should have copied into your notebook.

$R_1 =$ 506 Ω	$R_2 =$ 1010 Ω	$R_3 =$ 1480 Ω
$V_1 =$ 2.85 V	$V_2 =$ 5.71 V	$V_3 =$ 8.37 V
$I_1 =$ 5.6 mA	$I_2 =$ 5.6 mA	$I_3 =$ 5.6 mA

$R_{1+2} =$ 1516 Ω $\qquad$ $R_{1+2+3} =$ 3000 Ω

Note: R_{1+2} and R_{1+2+3} are measured values.



$V =$ 16.93 V $\qquad$ $V_{1+2} =$ 8.56 V

$V_{1+2+3} =$ 16.93 V

2. The voltage output of the power supply used to collect the sample data is 16.93 V.

3. The sum of the individual voltage drops across each resistor is equal to the total voltage output of the power supply.

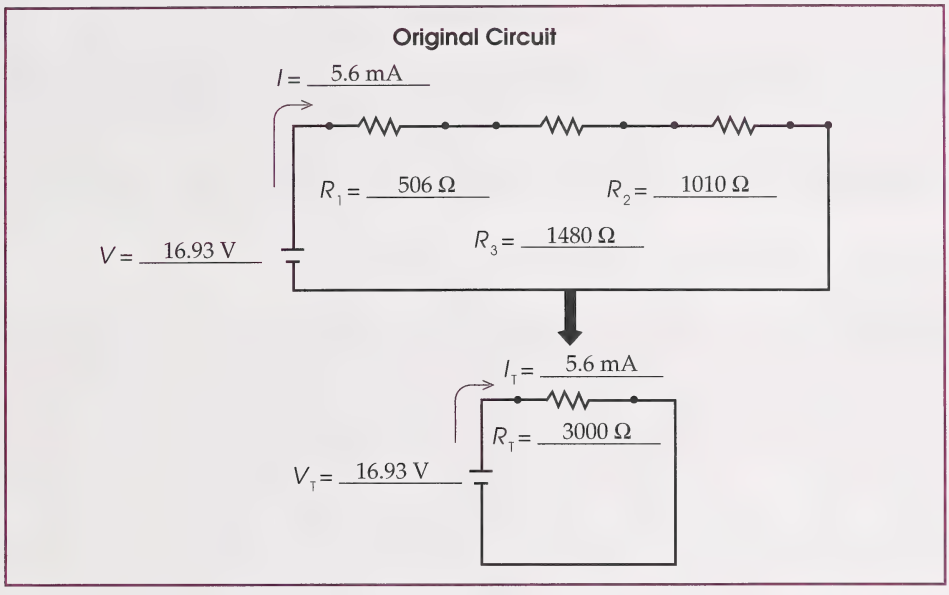
4. The electric potential energy of the electrons are raised to a certain level in the power supply and then this electric potential energy is used up by each of the resistors. In other words, there is conservation of energy.

5. The current is the same through each resistor. The individual currents are equal to the current output of the power supply.

6. There is only one path for the current to flow and that is why the current is the same throughout the whole circuit.

7. The sum of the individual values for resistance is equal to the total resistance of the circuit.

8.



9. $R_T = \dfrac{V_T}{I_T}$

$= \dfrac{16.93\,\text{V}}{5.6\,\text{mA}}$

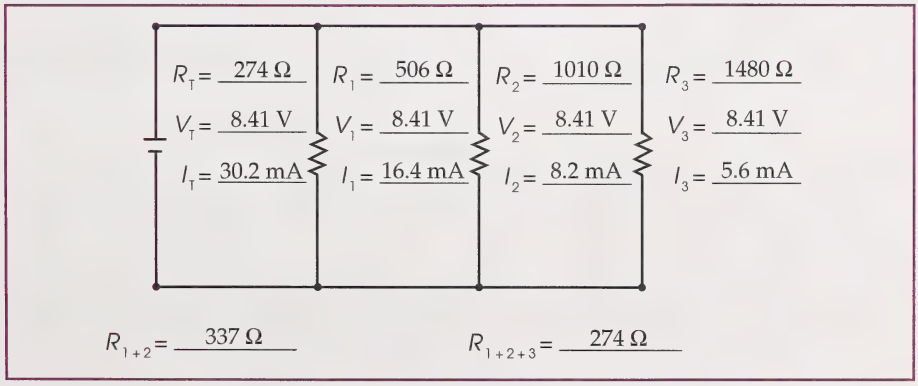
$= \dfrac{16.93\,\text{V}}{5.6\times10^{-3}\,\text{A}}$

$= 3023\,\Omega$

$= 3.0\times10^{3}\ \Omega$ (2 significant digits)

The theoretical value is close to the measured value. The difference is only 23 Ω, which is less than a 1% error.

10. The follow is a sample data chart like the one that you should have copied into your notebook.



11. The voltage drop across each resistor equals the voltage output of the power supply.

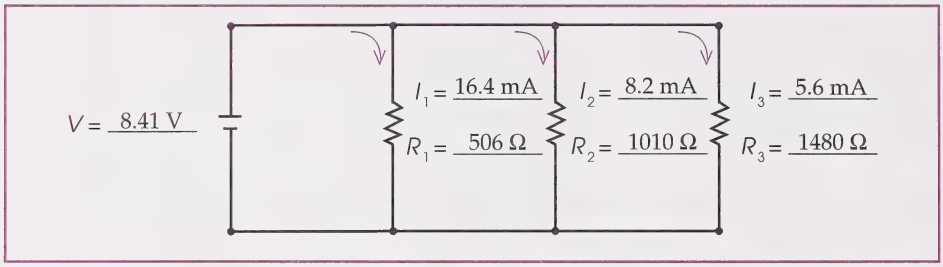
12. The potential drop across each path is the same because the battery does a certain amount of work to the electrons and, regardless of the path they take, the electrons must lose all of that energy by the time they reach the battery. Therefore, each path has the same drop in electric potential difference.

13. The total current provided by the power supply is equal to the sum of the individual currents in the branches.

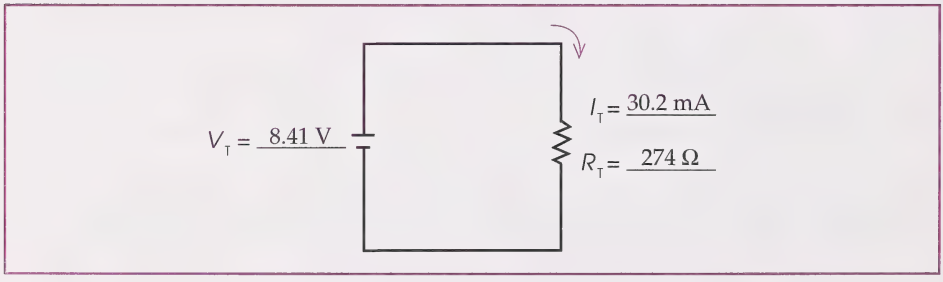
14. The total current equals the sum of the currents in each branch because charge is conserved.

15. The total resistance of all three resistors connected in parallel is less than the individual resistances of all the three resistors.

16.



If all the resistors were replaced with an equivalent single resistor, R_T, such that the total current did not change, the circuit would look like this.



17. $$R_T = \frac{V_T}{I_T}$$
$$= \frac{8.41\,\text{V}}{30.2\,\text{mA}}$$
$$= \frac{8.41\,\text{V}}{30.2 \times 10^{-3}\,\text{A}}$$
$$= 278\,\Omega$$

The theoretical and actual values are very close. Their difference is only 4 Ω, giving a percent error of less than 2%.

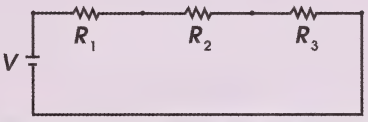
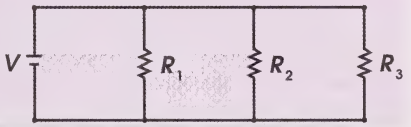
18. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$= \frac{1}{506\,\Omega} + \frac{1}{1010\,\Omega} + \frac{1}{1480\,\Omega}$

$R_T = 275\,\Omega$

The measured value and the calculated value are nearly the same. The difference is only 1 Ω, giving a percent error of less than 1%.

19.

Questions for Comparison	The Series Circuit 	The Parallel Circuit 
If another resistor is added, what would be the effect on the equivalent resistance of the whole circuit?	Adding another resistor to this circuit would increase the equivalent resistance of the whole circuit.	Adding another resistor to this circuit would decrease the equivalent resistance of the whole circuit.
If another resistor is added, what would be the effect on the total current drawn by the circuit?	Adding another resistor would increase the equivalent resistance and would therefore decrease the current drawn by the circuit.	Adding another resistor would decrease the equivalent resistance and would therefore increase the current drawn by the circuit.
If R_3 was simply disconnected and removed from the circuit, what changes would occur in this circuit?	If R_3 was disconnected and removed, then the circuit no longer exists as a closed loop because R_2 would no longer connect to the negative side of the voltage supply. This would have the effect of breaking the circuit and causing the current to immediately drop to zero.	If R_3 was disconnected and removed, then the circuit would still be able to flow through R_1 and R_2. The equivalent resistance would increase since there would be one less path for electrons to follow. Therefore the total current drawn from the voltage supply would be less.

20. If the bulbs are connected in series, then when one bulb burns out the whole set stops working. The other problem is that since you don't know which of the bulbs is defective, you are faced with the task of testing every bulb.

21. This circuit is a parallel circuit because people want the convenience of being able to turn off or on one bedroom light without having to do the same to all the others. Parallel circuitry allows for this kind of convenience. All the circuits shown in a home's electrical panel are parallel circuits for this same reason.

22. When the kettle was plugged in another branch was created in an already full parallel circuit. The equivalent resistance of the whole circuit dropped and therefore the current required increased. The current increased beyond the safe operating limit set by the size of the circuit breaker. The breaker stopped the current flowing to this circuit to eliminate a possible fire hazard that might be caused if the wires in the wall overheated.

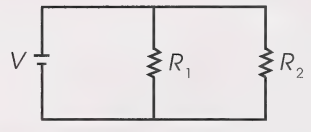
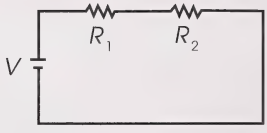
Section 2: Follow-up Activities

Extra Help

1.

Term	Definition	Symbol	Unit(s)	Related Equation(s)
potential difference	the ratio of the change in electric potential energy per unit of charge	V	joules per coulomb or volts	$V = \frac{E_e}{q}$
current	the ratio of the amount of charge that passes a point per unit of time	I	coulombs per second or amperes	$I = \frac{q}{t}$
electric field across two parallel plates	this uniform electric field can be calculated as the ratio of the voltage to the plate separation	$\lvert\vec{E}\rvert$	newtons per coulomb or volts per metre	$\lvert\vec{E}\rvert = \frac{V}{d}$
resistance	the ratio of the potential difference across a conductor to the current flowing through the conductor	R	volts per ampere or ohms	$R = \frac{V}{I}$
electric power	the ratio of the electric energy used per unit of time	P	joules per second or watts	$P = IV$ $P = I^2R$
electric energy	the energy consumed by an electric circuit	E_e	joules	$E_e = Vq$ $E_e = Pt$

2.

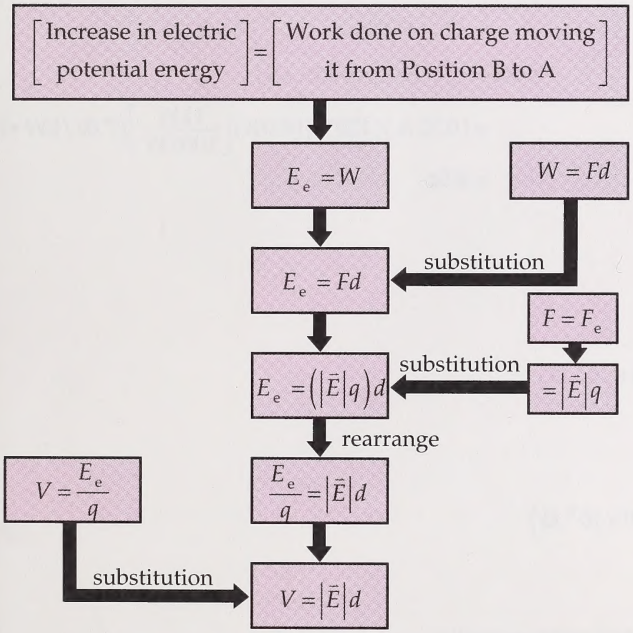
COMPARING SERIES AND PARALLEL CIRCUITS		
Type of Circuit	parallel circuit	series circuit
Schematic Diagram		
General properties of this type of circuit	• This circuit has the same potential difference across each branch. The current flowing through each branch could be different. • Adding more resistors causes the equivalent resistance to drop and more current to be drawn. • Removing one of the resistors causes less current to be drawn, but current still flows through the remaining resistor(s).	• This circuit has only one loop for current. The current is the same through each resistor but the potential difference across each resistor could be different. • Adding more resistors causes the equivalent resistance to increase and less current to be drawn. • Removing one of the resistors causes a break in the circuit. Current can no longer flow.

Enrichment

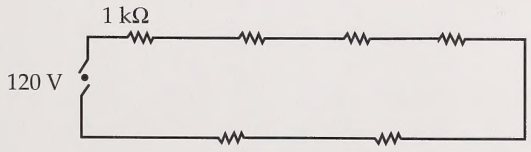
1. Georg Simon Ohm was born the son of a mechanic in Erlangen, Bavaria, in 1787. Ohm was a high school teacher who wanted to teach at a university, but in order to do this he had to first publish some important research work. Ohm decided to study one of the most exciting new scientific fields of this time—current electricity. Ohm focused on exploring the relationship between the potential difference across a conductor and the resulting electric current that flowed through it. His results could be summed up in the equation now known as Ohm's law ($V = IR$).

   Unfortunately, the scientists of his day were very critical of his work and would not accept his results. The criticism was so severe that he was forced to resign his position as a high school teacher and had to live the next six years in poverty. As time passed, his work became known outside of Germany and scientists in other countries began to honour his work and accomplishments. Eventually, he was asked to teach at the University of Munich, where he taught for the last five years of his life.

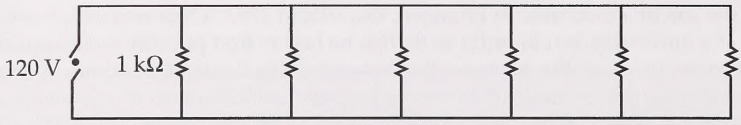
   His work is honoured to this day by naming the unit of resistance the ohm.

2. 

3. a. Series



Parallel



b. Series

$$R_T = \sum R$$
$$= 6(1.0\,\text{k}\Omega)$$
$$= 6.0\,\text{k}\Omega$$

$$I_T = \frac{V_T}{R_T}$$
$$= \frac{120\,\text{V}}{6.0\times10^3\,\Omega}$$
$$= 0.020\,\text{A}$$

$$\text{Cost} = I_T V_T t(\text{cost/kW}\bullet\text{h})$$
$$= (0.020\,\text{A})(120\,\text{V})(8.0\,\text{h})\left[\frac{1\,\text{kW}}{1000\,\text{W}}\right](7.0¢/\text{kW}\bullet\text{h})$$
$$= 0.13¢$$

Parallel

$$\frac{I}{R_T} = \sum\frac{1}{R}$$
$$= 6\left(\frac{1}{1000}\right)$$
$$R = 167\,\Omega$$

$$I_T = \frac{V_T}{R_T}$$
$$= \frac{120\,\text{V}}{167\,\Omega}$$
$$= 0.72\,\text{A}$$

$$\text{Cost} = I_T V_T t(\text{cost/kW}\bullet\text{h})$$
$$= (0.72\,\text{A})(120\,\text{V})(8.0\,\text{h})\left[\frac{1\,\text{kW}}{1000\,\text{W}}\right](7.0¢/\text{kW}\bullet\text{h})$$
$$= 4.8¢$$

c. The series setup is cheaper.

d. Power in series per bulb $= I^2R$
$$= (0.020)^2\left(1.0\times10^3\,\Omega\right)$$
$$= 0.40\,\text{W}$$

Power in parallel per bulb $= I^2R$
$$= (0.12)^2\left(1.0\times10^3\,\Omega\right)$$
$$= 14.4\,\text{W}$$
$$= 14\,\text{W}$$

The bulbs in parallel would be brighter, but more expensive.

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